5.1 Overview

In choosing among several restoration alternatives and actions for given habitats or natural biological resources (Exhibit 5.1), the following general approach should be considered:

- The baseline condition and functioning of the natural resource needs to be understood and quantified, including the degree of variability that exists. Degree of injury and natural recovery should be assessed;

- Incident- and natural resource-specific restoration goals and objectives are defined. The overall goal of restoration is to make the environmneta and public whole through the return of the injured natural resources and services to baseline and compensation of interim losses;

- Actions are evaluated for feasibility, i.e., whether actions are possible in the context of the particular situation. Constraints include availability of services, materials and equipment; construction and operational considerations; need or capability of future restoration; and consistency with all applicable laws and regulations. Infeasible actions are eliminated from further analysis. When practical, tested methods should take preference over unproven methods;

- The relative scientific merits (effectiveness) of feasible actions are evaluated;

- The most cost-effective actions that meet the restoration goals and objectives should be selected (i.e., if two or more actions provide equal benefits, the least costly is the most cost-effective action); and

- The expected costs of each action (or set of actions performed together) should be compared with expected benefits (where benefit estimation is feasible at a reasonable cost) to estimate reduction in interim loss.

In the following sections, an evaluation of actions for each habitat and natural resource is made that considers technical feasibility, scientific merit (effectiveness and success), and cost (Exhibit 5.2). Each of the possible restoration actions will be evaluated relative to the natural recovery alternative (no direct or primary action) and to all other feasible alternatives and actions for the habitat or resource. A system for selecting among alternatives and actions is developed that supports the decisionmaking framework (Chapter 6).

Exhibit 5.1 Restoration actions for each alternative.

1. Natural Recovery (no action)
   - Monitoring
2. Direct Restoration
   - a. Direct Habitat Restoration
     - Contaminant Removal
     - Reconstruction
     - Replanting
     - Accelerated Degradation
     - Monitoring
     - Maintenance
   - b. Direct Resource Restoration
     - Restocking
     - Harvest Alteration
     - Enhancement
     - Monitoring
     - Maintenance
3. Rehabilitation
   - a. Habitats
     - Contaminant Removal
     - Reconstruction
     - Replanting
     - Accelerated Degradation
     - Monitoring
     - Maintenance
   - b. Resource
     - Stocking
     - Harvest Alteration
     - Enhancement
     - Monitoring
     - Maintenance
4. Replacement
   - a. Habitats
     - Enhancement
     - Creation
     - Monitoring
     - Maintenance
   - b. Resources
     - Stocking
     - Harvest Alteration
     - Enhancement
     - Monitoring
     - Maintenance
   - c. Non-biological Services
     - Recreational
     - Commercial
     - Cultural
5. Acquisition of Equivalent Resources
   - Acquire property rights
   - Protection or management
6. Combinations of the Above

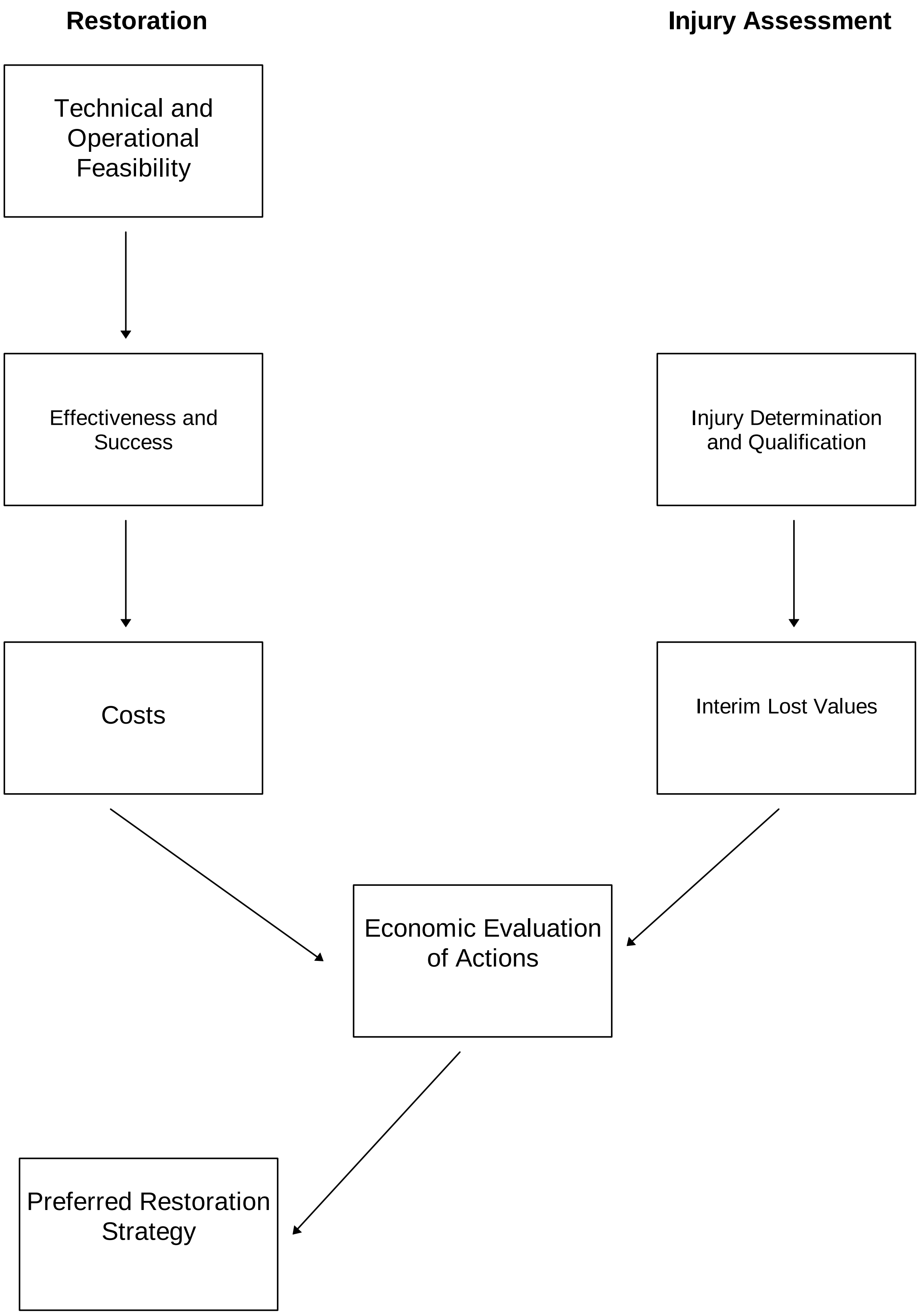

Exhibit 5.2 Process for recommending a restoration strategy.

In many cases, a qualitative assessment will show quite clearly that certain actions are either preferable or not viable. Also, the alternatives of direct restoration, rehabilitation, and replacement are preferable to acquisition of equivalent natural resources in the context of OPA. Thus, a first cut ranking system of actions may be made at this qualitative level. However, this evaluation should have some basis (i.e., feasibility or habitat recovery potential).

In addition to the assessment that must be assessed for a given natural resource, an evaluation among natural resources must also be made. While a particular action may not be effective at restoring the targeted resource, it may be of net benefit to all injured natural resources to perform that action. For example, cleaning oil off shorelines may be injurious to shoreline biota, but may reduce contamination effects on wildlife and other ecosystems.

Another aspect of the assessment involves the replacement of natural resources and their services by altering, and so impacting, other natural resources, for example in using wetland creation to replace affected wetlands and wildlife services. If an injured wetland is expected <u>never</u> to recover, then creation of two or more acres for every acre injured is appropriate. But if the injured wetland is expected to recover over some finite period, then a mitigation ratio of 2 or more might be over-compensating the public, if the created wetlands are expected to provide services in perpetuity. The total discounted flow of services in the created habitat should be just equal to the total discounted flow of services lost from the injured wetland. For more discussion of the methods for determining appropriate level of compensation, the reader is referred to the OPA regulations.

In his review of wetlands mitigation planning, Kruczynski (1989) makes the following points. The order of preference for mitigation (of wetlands loss) should be: (1) direct restoration of a degraded wetland (which may be other than the wetland injured), (2) creation of new wetland in an upland area not a wetland in the recent past, (3) enhancement of one or more functions of an existing wetland, (4) habitat exchange, which amounts to creating a wetland in an area which is presently a functional aquatic habitat of another type, and (5) preservation of existing habitat. He argues that choice (1) is more likely to be successful than choice (2). Both enhancement and exchange involve the replacement of some natural resources and services by others presumably more desirable. Preservation should not normally be considered compensatory for loss, since there is no net gain to the public. However, where preservation can be shown to prevent a future loss and where protection is in perpetuity this alternative may be a viable option.

Kruczynski (1989) also suggests compensatory mitigation ratios for wetlands to make up for the fact that restoration and replacement do not necessarily provide 100% of the services of natural wetlands (and in fact are really rehabilitation in the sense of the definitions used in this document). What is sought is functional equivalency to the wetland area injured. He suggests minimum ratios of 1.5:1 for restoration, 2:1 for creation, and 3:1 for enhancement, meaning that much more habitat should be restored, created, or enhanced to compensate for a unit loss of natural habitat. These ratios imply, however, that the converted habitat in the compensation (i.e., at the new site) is not of equivalent value to the (wetland) habitat created. These tradeoffs, need to be carefully evaluated.

5.1.1 Quantification of Recovery

In order to select the most appropriate restoration actions, quantitative information on the rate and level of recovery of natural resources and their services should be evaluated for each action and compared to other actions. As an illustration of this type of evaluation, a simple recovery model has been developed. An outline of the recovery model is as follows.

In the case of natural recovery, recovery is related to the concentration (or mass per unit area) of oil remaining in the habitat over time if that concentration is toxic. Analyses by Reed et al. (1989) have shown that for marine intertidal habitats (and others as well) concentration as a function of time may be described by a first-order decay curve, which may be written as:

$$\frac{dC}{dt} = -(d + r)C = -kC \qquad \textbf{(1)}$$

or

$$C = C_o \, e^{(-d-r)t} = C_o \, e^{-kt} \qquad \textbf{(2)}$$

where

- C = concentration (or mass per area)
- t = time
- C_o = C at t=0
- d = degradation rate
- r = physical (natural) removal rate
- k = d + r = decay constant measuring total loss rate

For some restoration actions, the values of d (e.g., bioremediation) or r (e.g., chemical remediation) are increased. Thus, C = f(t) may be described by changing the value of k at a certain time of restoration, t_r. For other actions (e.g., mechanical removal), a fraction of C is removed at t_r (Exhibit 5.3).

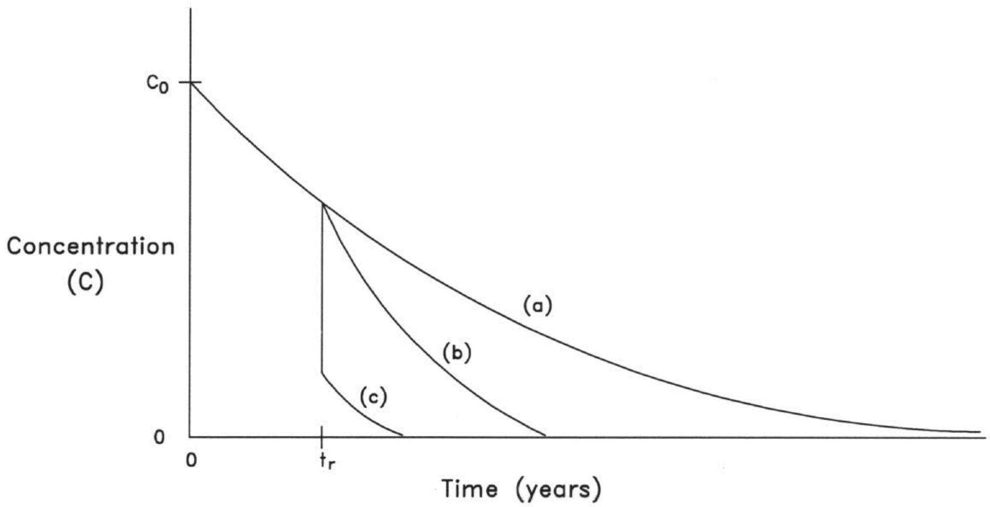

Exhibit 5.3 Concentration as a function of time of recovery: (a) = natural recovery; (b) = increased removal and/or degradation rate beginning at time t_r; (c) = bulk removal of contaminant at time of restoration t_r.

To quantify recovery with some assumed action taken (including natural recovery), loss of functionality is related to concentration as well as to the time lag in reestablishment of habitat and resource populations. In the case where the effects are small and/or sublethal, such that the habitat structure is not disrupted and recovery in the absence of toxicity would be nearly immediate, the loss of functionality is a function of concentration. The simplest model is, which may be quantifiable for a number of habitats, is that loss, L, is proportional to concentration. Below some threshold for effects, at $C = C_{min}$, $L = 0$; for $C \geq C_{max}$, $L = 1.0$, and for $C_{min} \leq C \leq C_{max}$, L increases linearly from 0.0 to 1.0 (Exhibit 5.4). The function for $C_{min} \leq C \leq C_{max}$ is:

$$L = \frac{(C - C_{\min})}{(C_{\max} - C_{\min})} \qquad \textbf{(3)}$$

For restoration actions where all toxic concentrations are removed, there is a natural recovery curve for the reestablishment of habitat and resource populations. This recovery curve is likely sigmoidal (Exhibit 5.5) and as described by the following:

$$\frac{dPr}{dt} = P_R \, (r_b - r_b \; P_R) \qquad \textbf{(4)}$$

where P_R is the portion of full functionality at full recovery and r_b is a constant measuring rate of recovery. This function may be parameterized by estimating the time to 99% recovery (trec at L = 0.01%). Solving (analytically) the above equation for P_R, assuming $P_R = 0.01$ at $t = t_e$ (i.e., an initial condition of total loss, where t_e is the time where the habitat begins to reestablish itself) yields:

$$P_R = 1 \,/\, \left(1 + 99 \; e^{-r_b(t - t_e)}\right) \qquad \textbf{(5)}$$

The value of r_b may be estimated from an estimate of P_R at t, under conditions of no contamination and an initial condition of total loss. If $P_R = 0.99$ and $t_e = 0$, then $t = t_{rec} = 9.19/r_b$.

In the absence of toxic concentrations, replanting, restocking and other restoration actions may accelerate the recovery curve by decreasing time to recovery (Exhibit 5.5). In Chapter 3, recovery rates were estimated for various natural resources, if quantitative information is available. Recovery estimates are summarized in Section 5.2 below. Dependent natural resources might be assumed to recover proportionate to the habitat recovery, in the absence of specific information.

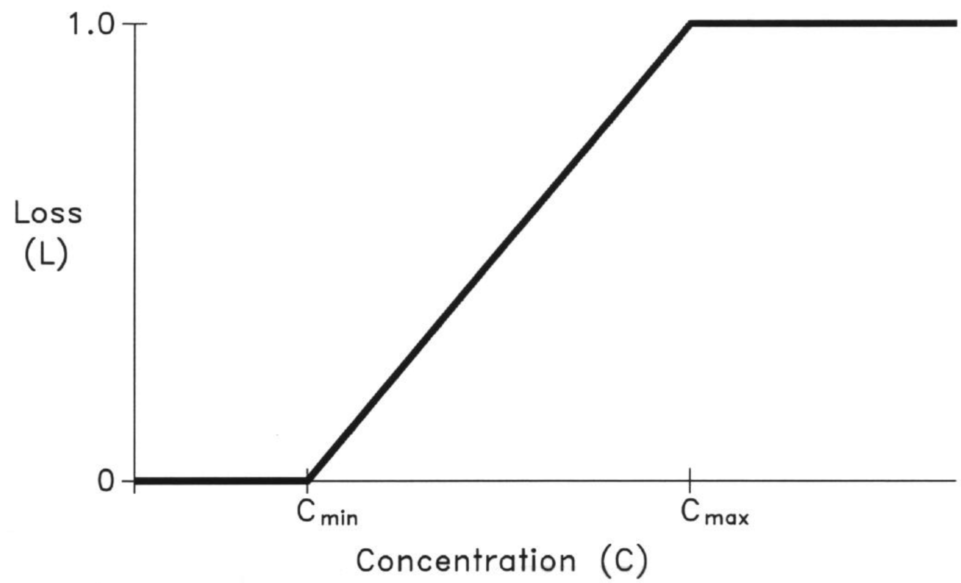

Exhibit 5.4 Hypothetical linear relationship between percent loss (L) and concentration (C).

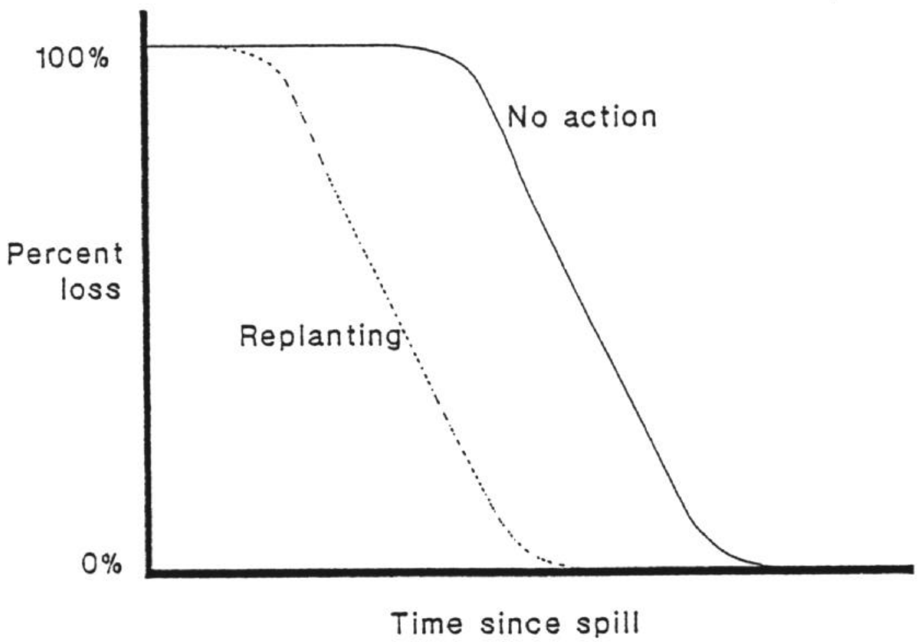

Exhibit 5.5 Case where injury is near 100% loss and restoration increases the rate of recovery.

For restoration actions where toxicity remains and reestablishment of habitat natural and populations is also required, the recovery curve needs to reflect both influences. Since remaining toxicity would inhibit the habitat and population reestablishment, the most likely model is multiplicative one of the two functions (i.e., $f_1(C) * f_2(t_e)$, where $f_1 = (1\text{-}L)$ is the function of L related to concentration (Equations 2 and 3) and f_2 is the function of P_R related to time of reestablishment (t_e) using Equation (4)). The value of t_e is the time since restoration actions were completed or since maximum concentrations were present in the case of natural recovery.

The recovery model described above could be applied to habitats, natural resources, or non-biological services (i.e., recreation), and actions for which the parameters may be quantified. The needed parameters for the simplest model are degradation rate (d), physical removal rate (r), C_{min} (threshold for effects), C_{max} (threshold for 100% loss), and time of 99% recovery (t_{rec}) or some other known percent recovery under no contamination, such that r_b may be calculated. For actions that accelerate recovery, the time to 99% recovery with the action (t_{rec}') may be used to calculate r_b' for equation (5). This yields a quantification of the portion of full recovery (P) as a function of time for the habitat or natural resource and action, where $P = P_R\ (1\text{-}L)$.

Various restoration actions and combinations thereof may then be compared quantitatively using these recovery curves. The analysis described in Exhibit 5.6 shows a hypothetical comparison of no action versus a selected action. The gain from the action is area B minus area A (B-A) from the exhibit, or the integrated area under each of the two curves of L = f(t). Several actions may then be compared to determine the action providing the largest gain (B-A).

Exhibit 5.7 gives some quantities for parameters for sample applications of the recovery model. Exhibit 5.8 gives resulting times to 99% recovery for the hypothetical example cases where the initial concentration is lethal to the habitat and te is taken as t at $C = C_{max}$ in Equation (2).

The cases in Exhibits 5.7 and 5.8 represent various habitat types as defined by t_{rec} (i.e., time to 99% recovery from total loss under conditions of no contamination) and k (degradation plus physical removal rate, 1/day). As can be seen in Exhibit 5.8, higher values of k speed recovery to approach that of the no contamination scenario. When k is high, restoration actions (such as doubling k or removing half of the contamination manually) performed at one year after the discharge do not have a significant effect, while they do when k is low. The hypothetical actions have much more effect if performed sooner, such as at one month. This is because of the exponential loss of concentration over time. Once concentration has fallen below C_{min}, recovery is unaffected by the removal of C or increase of k. The following gives time to $C = C_{min}$ in years for various values of k and C_o.

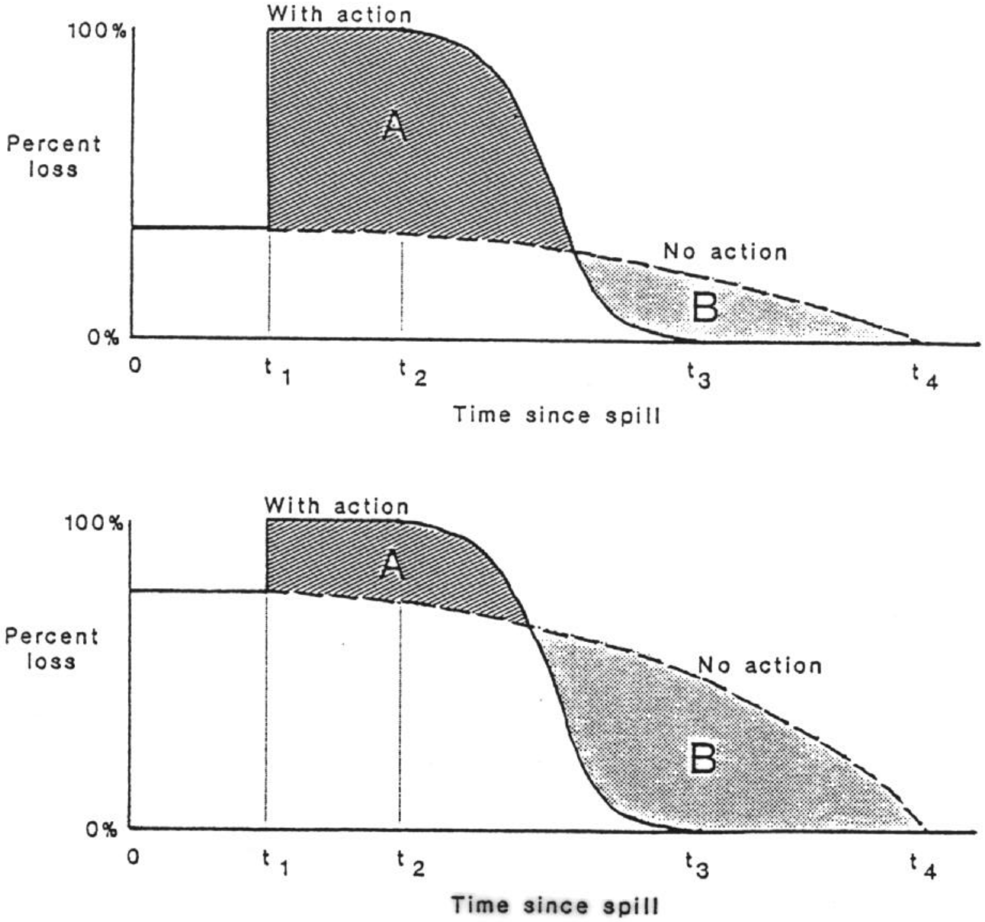

Exhibit 5.6 Schematics showing cases where restoration will or will not reduce the injury as measured by percent loss of services. Area A is the additional loss and area B is the gain resulting from performing the restoration action. The times of events are: t_1 = time work on site begins, t_2 = time work on site is completed, t_3 = time recovery is 99% complete assuming restoration action performed, t_4 = time habitat is no longer toxic assuming no restoration action is performed (i.e., assuming natural recovery). Restoration will not reduce losses if the additional loss imposed by the action is greater than the gain (upper graph, area A > area B). Restoration will reduce the injury if the gains outweigh the losses (lower graph, area A < B)

Exhibit 5.7 Estimated removal rates from Reed et al. (1989) and times to recovery when no contamination is present for several habitats.

Habitat	r(1/day)	t_{rec} (yrs) (no contamination)
Marine Exposed Rocky Shore	0.1	5
Marine Sheltered Rocky Shore	0.01	5
Marine Gravel Beach	0.005	3
Marine Sand Beach	0.01	3
Saltmarsh	0.001	15

Exhibit 5.8 Time to recovery to 99% of full function, assuming C_{min} = 0.1 ppm, C_{max} = 100.0 ppm, d=0.001/day, C_o=500 ppm, and the listed values for the parameters k and t_{rec} with no contamination.

t_{rec} (yrs) if no contamination	5	5	5	5	3	3	15
k (1/day)	0.101	0.011	0.002	0.001	0.011	0.006	0.002
Time to 99% recovery (yrs) natural recovery	5.0	5.4	8.5	16.8	3.4	3.8	17.2
Time to 99% recovery (yrs) if double k at t = 1 yr	5.0	5.4	6.6	9.0	3.4	3.7	16.6
Time to 99% recovery (yrs) if remove 50% of C at t = 1 yr	5.0	5.4	6.1	6.7	3.4	3.7	16.1
Time to 99% recovery (yrs) if double k and remove 50% of C at t = 1 yr	5.0	5.4	6.0	6.0	3.4	3.7	16.0
Time to 99% recovery (yrs) if double k at t = 1 mo	5.0	5.2	6.1	8.5	3.2	3.4	16.1
Time to 99% recovery (yrs) if remove 50% of C at t = 1 mo	5.0	5.1	5.5	6.0	3.1	3.2	15.5
Time of 99% recovery (yrs) if double k and remove 50% of C at t = 1 mo	5.0	5.1	5.3	5.5	3.1	3.2	15.3

k (1/day)	t (yrs) to $C = C_{min}$ where C_o = 500 ppm	t (yrs) to $C = C_{min}$ where C_o = 1 ppm
0.101	0.23	0.06
0.011	2.12	0.57
0.006	3.89	1.05
0.002	11.67	3.15
0.001	23.33	6.31

The above exhibit points out that improvement in recovery by removal of contamination can only be made if removal is accelerated or performed while concentrations are still above toxic thresholds. While this makes intuitive sense, it can be forgotten in practice in the urgency of trying to do something constructive. Thus, it is desirable to determine if remaining oil is indeed toxic and how long it is expected to remain at toxic concentrations. Otherwise, unnecessary and potentially harmful actions to cleanse the habitat may be unwisely undertaken.

It should also be noted that restoration actions that increase the rate of recovery ($r_{b'} > r_b$) are always beneficial to the natural resource (e.g., Exhibit 5.5). The model (equation 5 employed for the natural recovery case using r_b compared to the restoration action case of $r_{b'}$) can quantify the gain of the action.

This type of quantitative analysis allows ranking of restoration actions based on natural and restoration-enhanced recovery rates. It also allows quantification of gains for cost-benefit analyses. Such quantification can support the decisionmaking process in restoration planning.

The simple recovery model's calculations are set out as formulas for use in real situations or where the required data are available. The recovery model also serves as a construct to assist in the decisionmaking process. More sophisticated models of recovery are desirable where data may be obtained to support them. It should be noted that the available data for even the simple model may have considerable uncertainty associated with it. Probablistic modeling, sensitivity analysis, and quantification of uncertainty will elucidate risks of various actions.

5.2 Habitat Restoration and Mitigation

Exhibits 5.9 to 5.46 summarize the alternatives and actions that may be considered for habitat restoration. Restoration of a habitat includes restoration of biota and their services. Discussion of these follow.

It should again be emphasized that these are <u>actions</u> for consideration. The following discussion is not meant to be a cookbook for restoration, but to provide a basis for decision making. These exhibits point to a list of actions available for the circumstances identified. Consideration should then be made as to whether the actions will actually improve recovery under the circumstances.

5.2.1 Estuarine and Marine Wetlands

5.2.1.1 Saltmarshes

Conditions where various alternatives and actions are appropriate are summarized in Exhibits 5.9 to 5.12. Appropriate restoration actions are determined in a hierarchical fashion, depending on whether or not the oil has penetrated the substrate, is adhering to the substrate, is recoverable, the vegetation is contaminated, and vegetative (and rhizome) mortality has occurred. Actions for cases where oil has not penetrated and is not adhering to the substrate (and may or may not be recoverable) are presented in Exhibit 5.10. Exhibit 5.11 summarizes actions for cases where oil has not penetrated the substrate but is adhering to the substrate (and so is not recoverable). Exhibit 5.12 describes cases where oil has penetrated the substrate. The answers to the above 5 questions will lead the user to the available alternatives and actions for the circumstances.

Because of the potential for serious injury to saltmarsh habitats from response and restoration activities, all actions must be performed in a manner that does not result in unnecessary further injury. For example, vegetative cropping and low pressure flushing should be performed from boats in order to avoid injury to marsh substrate and vegetation root structures from trampling.

Natural recovery, vegetative cropping, low pressure flushing, replanting, and monitoring are all technically feasible. Bioremediation techniques, while potentially promising, were not tested extensively in saltmarsh habitats. Sediment removal, replacement, and replanting, along with creation, are technically feasible, but not necessarily effective or successful.

Due to the potential for serious injury, and a large body of literature documenting relatively rapid recovery on a time scale of years, natural recovery should receive first consideration in cases where oiled marshes are to be restored. If a marsh is so heavily oiled that the oil must be removed in order to prevent toxic effects on biota and/or continuing recontamination, low pressure flushing, cutting above-ground vegetation, or a combination of the two should be considered as secondary actions. Low pressure flushing can be effective if performed soon after oiling, provided oil has not penetrated the marsh substrate. If recovery does not proceed after 1-2 growing seasons, replanting should be evaluated as a tertiary action. Sediment removal and replacement should only be considered if vegetation and rhizomes are dead and the substrate is so contaminated that it impedes recovery.

The above scientific assessment does not include any technically infeasible or difficult techniques. The actions are also much less expensive than other proposed restoration actions. Thus, scientific merit (expectation of increased recovery rate) should drive the decisionmaking process for restoration of saltmarshes. Alternatives and actions are summarized in Exhibit 5.29.

It should be noted that recovery times given are based primarily on structural observations of vegetation, although data on faunal and ecological function recovery are available and influence the recovery time estimates.

5.2.1.2 Mangrove Swamp

Conditions where various alternatives and actions are appropriate are summarized in Exhibits 5.13 to 5.15. Appropriate restoration actions are determined in a hierarchical fashion, depending on whether or not the oil has penetrated the substrate, is adhering to the substrate, is recoverable, the vegetation is contaminated and plant mortality has occurred. Actions for cases where oil has not penetrated and is not adhering to the substrate are presented in Exhibit 5.14. Exhibit 5.15 summarizes actions for circumstances where oil has not penetrated but is adhering to the substrate. Exhibit 5.15 also describes circumstances where oil has penetrated the substrate.

Because of the potential for serious injury to mangrove habitats from response and restoration activities, all actions should be performed in a manner that does not result in further injury. For example, low pressure flushing should be performed from boats in order to avoid injury to the substrate, root structures, and mangrove seedlings by trampling. Cutting of vegetation and excavation of channels is unlikely to be an effective action. Such actions have resulted in increased oiling of the mangrove habitat injured in the Refineria Panama discharge (Jackson and Keller, 1991).

Natural recovery, low pressure flushing, replanting, and monitoring are all technically feasible. Bioremediation techniques have not been tested in mangrove habitats.

Natural recovery should receive primary consideration where oiled mangrove habitats are to be restored. If the environment is so heavily oiled that the oil must be removed in order to prevent toxic effects on biota and/or continuing recontamination, low pressure flushing of substrate and mangrove root systems may be performed as a secondary action, provided oil has not penetrated the substrate. If recovery does not proceed by recolonization from adjacent unoiled areas, replanting may be employed as a tertiary action. Note that sediment removal and replacement is not an effective action for mangrove restoration.

The above scientific assessment does not include any technically infeasible or difficult techniques. The actions are also much less expensive than other proposed restoration actions. Thus, scientific merit (expectation of increased recovery rate) should drive the decisionmaking process for restoration of mangrove swamps. Exhibit 5.30 summarizes alternatives and actions.

Recovery time estimates are for vegetation. Little data exist on mangrove habitat faunal recovery (except as reviewed in Section 3.2.1.2). It is assumed that fauna recovery proceeds in parallel with the vegetation.

5.2.2 Freshwater Wetlands

5.2.2.1 Emergent Wetlands

The conditions where various alternatives and actions are appropriate are the same for freshwater emergent wetlands as for saltmarshes. Thus, Exhibits 5.9 to 5.12 apply to both these habitats, as well as the discussion in Section 5.2.1.1. Exhibit 5.29 also summarizes actions in freshwater emergent wetlands, the feasibility issues, recovery rates, and costs being similar in both marsh habitats.

5.2.2.2 Scrub-Shrub Wetlands

The conditions where various alternatives and actions are appropriate are the same for all swamps, including mangrove swamps, freshwater scrub-shrub wetlands, and freshwater forested wetlands. Thus, Exhibits 5.13 to 5.15, Exhibit 5.30, and the discussion in Section 5.2.1.2 apply to this habitat as well.

5.2.2.3 Forested Wetlands

The conditions where various alternatives and actions are appropriate are the same for all swamps, including mangrove swamps, freshwater scrub-shrub wetlands, and freshwater forested wetlands. Thus, Exhibits 5.13 to 5.15, Exhibit 5.30, and the discussion in Section 5.2.1.2 apply to this habitat as well.

5.2.2.4 Bogs and Fens

Bogs and fens have developed over centuries of accumulation of peat and require extremely long recovery times (decades to centuries) following any alteration or removal of the substrate. For this reason, the only recommended alternatives and actions are natural recovery and bioremediation (Exhibit 5.16). The latter remains untested, but may be helpful to speed degradation of oil contamination. Costs for this action are unknown, but presumably similar to those for saltmarshes and emergent wetlands (Exhibit 5.29).

5.2.3 Vegetated Beds

5.2.3.1 Macroalgal Beds (Estuarine and Marine)

5.2.3.1.1 Intertidal Macroalgal Bed

The important elements of intertidal macroalgal bed restoration are, to a large extent, coincident with those for the rocky intertidal area. To the extent that the intertidal macroalgal bed is unique, it is considered in Exhibits 5.17 and 5.34. Careful cleanup (in both the response and restoration context) to avoid aggravating injuries is called for. Vegetative cropping may be needed if oil adheres to the vegetation. While replanting is proposed as a potential action, it remains untested as viable.

5.2.3.1.2 Kelp Bed

Alternatives and actions for kelp bed restoration are summarized in Exhibit 5.18 and Exhibit 5.35. Contaminated vegetation may be cropped. In most cases it is expected that natural recovery will be the action of choice. The time to full community recovery is uncertain because the faunal response to oil discharges is largely unknown. Replanting methods exist but have not been used in restoring oil discharge injuries. Herbivore control might be needed during the period of restoration to accelerate recovery.

5.2.3.2 Seagrass Beds

Seagrasses do not appear to be especially sensitive to oil discharges but their faunal communities may be quite sensitive. Restoration actions for seagrass beds are summarized in Exhibits 5.19 and 5.36. It is important to note that maintaining the integrity of the sediment may be important to restoration efforts whether or not replanting is attempted (Zieman et al., 1984). Also, off-site restoration, if chosen, should only be attempted in areas where seagrass is known to grow (e.g., a degraded seagrass bed in an areas where the cause of degradation is believed to have abated) (Zieman and Zieman, 1989). As with other complex habitats, the time to recovery for the plants can be projected. However, there exists only a vague idea of how rapidly the community is restored to full function. It is generally assumed that a structurally-restored grass bed will recolonize with its typical fauna from surrounding uninjured areas.

5.2.3.3 Freshwater Aquatic Bed (Submerged and Floating Vegetation)

There is little information on recovery of freshwater aquatic beds from oil discharge impacts. These habitats are not always considered valued so much as a nuisance. Possible restoration actions are summarized in Exhibit 5.20 and 5.37. Some of the information in these exhibits, such as restoration time, are speculative in the absence of more data.

5.2.4 Mollusc (Oyster) Reefs

Alternatives and actions for oyster reef restoration are summarized in Exhibits 5.21 and 5.38. There is no available information on restoration of oyster beds in response to oil discharge injuries. If oysters survive the discharge, they may still require some period of depuration before they are useful as a fishery resource. Natural reseeding may be quite rapid in some places at certain times of year, but will have to be augmented under other conditions. Where the oyster bed is heavily injured through response efforts, reconstruction and reseeding may be appropriate.

5.2.5 Coral Reefs

Restoration alternatives and actions for coral reefs are summarized in Exhibit 5.22 and Exhibit 5.39. This information is based on a rather sparse history of coral reef recovery from oil discharge injury. Because coral is so slow-growing, it is reasonable to assume that when the reef has recovered, the community has recovered. Unfortunately, there is little data to support this supposition.

5.2.6 Estuarine and Marine Intertidal

5.2.6.1 Rocky Shores

Conditions where various alternatives and actions are appropriate in the restoration of rocky shores is outlined in Exhibit 5.23. The actions are for oil-affected estuarine, marine, and freshwater rocky (and artificial) shores. Exhibit 5.40 further describes these alternatives and actions, including restrictions to be effective, feasibility, recovery times, and costs. Restoration actions are determined based on the importance of biological verses non-biological services, whether oil has adhered to the surface, and access to the shoreline. Where biological services of the rocky shore are the primary concern, only natural recovery and possibly bioremediation are recommended. Non-biological services will be more important in certain recreational-use areas, harbors, and other high-use areas. The value of these non-biological services may justify such extreme measures (in terms of biological effects) as hot water washing and sandblasting. Concerns over contamination of nearby habitats and biota may justify more rigorous cleaning as well.

5.2.6.2 Cobble-Gravel Beaches

Restoration alternatives and actions for cobble-gravel beaches are outlined in Exhibit 5.24. The decision for choosing an action is determined first by the importance of biological verses non-biological services. When biological services are important, bioremediation may be considered in low energy environments. However, natural recovery should be the preferred alternative in high energy areas where fertilizers would not remain on the shoreline to be effective. Where non-biological services are important, or where contamination to other natural resources is a concern, the decision on restoration is determined by whether non-biological services or other natural resources should take precedence, and whether or not oil has penetrated the substrate. Exhibit 5.41 summarizes the possible actions. Sediment agitation includes berm relocation and sediment mixing.

5.2.6.3 Sand Beaches

Estuarine, marine, and freshwater sand beaches injured by oil may be restored by the actions outlined in Exhibit 5.25. Again, actions are determined by the importance of biological versus non-biological services, concerns for contamination of other nearby resources, the energy of the environment, and penetration of oil into the substrate. Actions are reviewed in Exhibit 5.42.

5.2.6.4 Intertidal Mud Flat

Exhibit 5.26 outlines the appropriate actions for restoration of marine, and estuarine intertidal mud flats, and freshwater silt-mud shores. This is also reviewed in Exhibit 5.43. Alternative actions depend on penetration of the oil into the substrate and the toxicity of contaminated sediment.

5.2.7 Estuarine and Marine Subtidal

5.2.7.1 Subtidal Rock Bottoms

Natural recovery is the only alternative for restoration of estuarine, marine, and freshwater rock bottoms (Exhibit 5.44).

5.2.7.2 Subtidal Cobble-Gravel, Sand, and Silt-Mud Bottoms

Estuarine and marine subtidal cobble-gravel, sand and silt-mud bottoms, and freshwater sand and silt-mud bottoms restoration actions are outlined in Exhibit 5.27. The appropriate action is determined by whether or not oil has penetrated the substrate and is at toxic concentrations. If not, natural recovery is likely preferable. If the sediment is toxic, removal or capping may be used depending on the physical characteristics of the discharge area. Alternatives and actions are summarized in Exhibit 5.45.

5.2.8 Riverine and Lacustrine Shorelines

5.2.8.1 Rock Shores

Freshwater rock shores would be treated the same as estuarine and marine rock shore. (See Section 5.2.6.1.)

5.2.8.2 Cobble-Gravel Shores

Freshwater cobble-gravel beaches would be treated the same as estuarine and marine cobble-gravel shore. (See Section 5.2.6.2.)

5.2.8.3 Sand Shores

Freshwater sand shores would be treated the same as estuarine and marine sand beaches. (See Section 5.2.6.3.)

5.2.8.4 Silt-Mud Shores

Freshwater silt-mud shores would be treated the same as estuarine and marine intertidal mud flats. (See Section 5.2.6.4.)

5.2.9 Riverine and Lacustrine Unvegetated Bottom

5.2.9.1 Rock Bottom

Natural recovery is the only alternative for restoration of estuarine, marine, and freshwater rock bottoms (Exhibit 5.44).

5.2.9.2 Cobble-Gravel Bottom

Exhibit 5.28 outlines available restoration actions for freshwater cobble-gravel bottoms. Where oil is adhering to or within the substrate, dredging and replacement may be considered. Streambed agitation is an action in riverine habitats. Exhibit 5.46 reviews these actions.

5.2.9.3 Sand and Silt-Mud Bottom

Freshwater sand and silt-mud bottoms would be treated the same as estuarine and marine subtidal bottoms of the same substrate type. (See Section 5.2.7.2)

5.2.10 Monitoring of Habitat Recovery

Monitoring costs have been estimated for a generic monitoring plan on a unit basis, the unit being an individual stratum or area of uniform habitat and environmental conditions. The description of the stratum is in Section 3.2.10. It is not a cost per unit area (such as $/ha), but rather a cost per stratum of affected habitat. Thus, Exhibits 5.29 to 5.46 contain the symbol M to refer to monitoring costs.

The value of M, monitoring cost per stratum, is estimated and described in Section 4.4. The costs of sediment monitoring (Section 4.4) are relevant to most habitat monitoring (M). Thus, the value of M would be on the order of $5,000 to $125,000 per year (1992$), depending on the complexity of the sampling and testing required.

5.3 Biological Populations

Alternatives and actions for biological resource populations may be summarized by the following:

- Natural recovery monitoring;
- Harvest alternation;
- Harvest refugia;
- Stocking, culturing, and seeding;
- Relocation;
- Habitat enhancement;
- Artificial structures;
- Facilitation of migration;
- Habitat protection and acquisition; and
- Replacement of services.

The specific actions are very species- and site-specific, and, therefore, cannot be summarized as concisely as for habitats in the previous section.

Factors that may need to be considered in developing and evaluating alternatives and actions include:

- Objectives should be carefully laid out and specific to the target species, life history requirements, and prevailing environmental conditions;

- Effectiveness and success should be rigorously evaluated. One should not assume that doing something has benefit. This has often been the case historically;

- The desire to solve waste disposal and other needs should not be considered a mitigating factor for restoration of injured natural resources unless proven to be truly effective at restoring those natural resources or services injured;

- Where possible, estimated costs should be weighed against restoration benefits;

- Attention should be paid to impacts on non-target species. The net benefits to all natural resources must be evaluated as a whole;

- In considering stocking efforts, the maintenance of genetic integrity in a wild stock is crucial. Also, possible introduction of disease should be considered;

- Enhancement actions may prove more effective than direct restoration of oil-injured natural resources because of lack of effectiveness of the latter;

- Changes in management practices resulting in benefits to both natural resources and their services is a preferred action.

- Restoration of habitats chronically affected by toxins and water quality problems or development can effectively replace oil-injured natural resources if replacement stocks are reduced but still viable; and

- Monitoring of injuries and recovery is crucial but may be difficult due to natural variability. Adequate financial resources must be applied to this part of the restoration effort to ensure the success of the restoration.

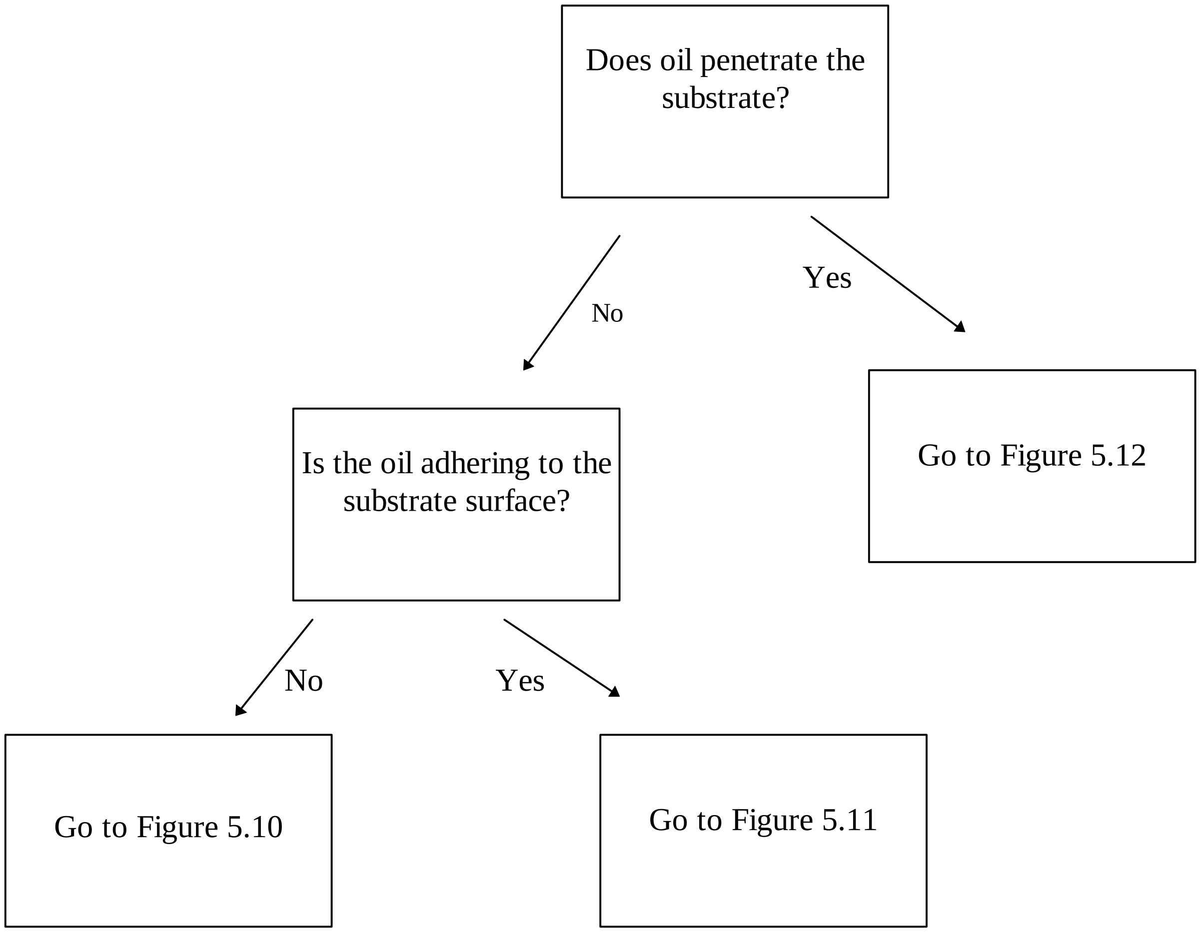

Exhibit 5.9 Decision diagram for restoration alternatives and actions for saltmarsh and freshwater emergent wetlands.

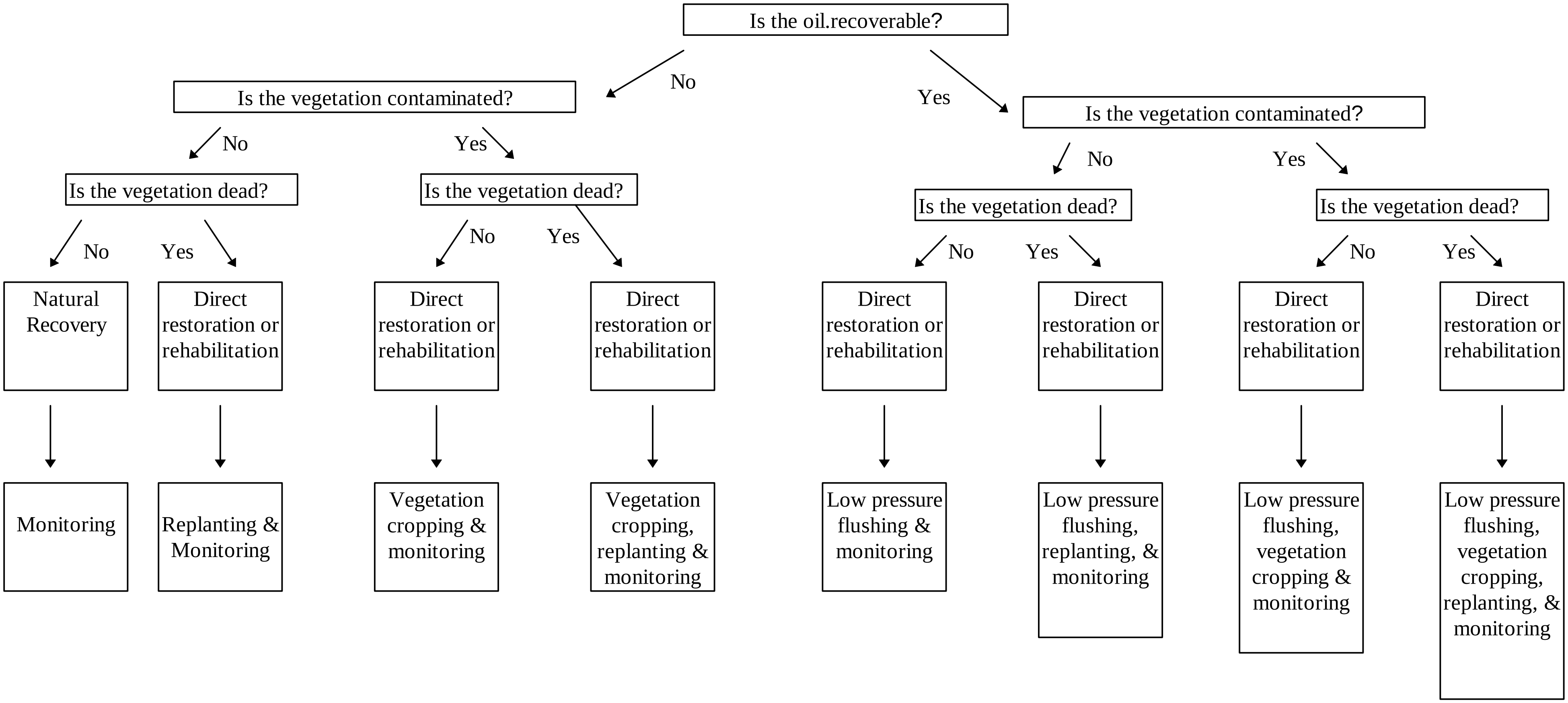

Exhibit 5.10 Decision diagram for restoration alternatives and actions for saltmarsh and freshwater emergent wetlands where oil has not penetrated the substrate and is not adhering to the substrate.

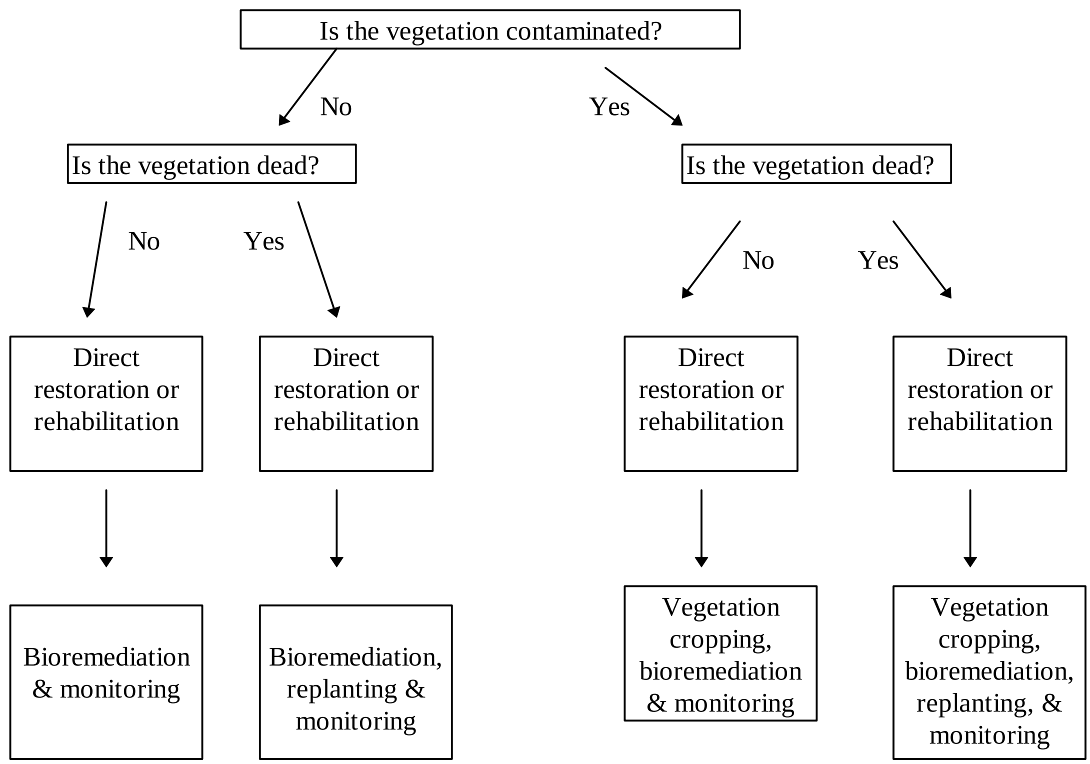

Exhibit 5.11 Decision diagram for restoration alternatives and actions for saltmarsh and freshwater emergent wetlands where oil has not penetrated but is adhering to the substrate (and so is not recoverable).

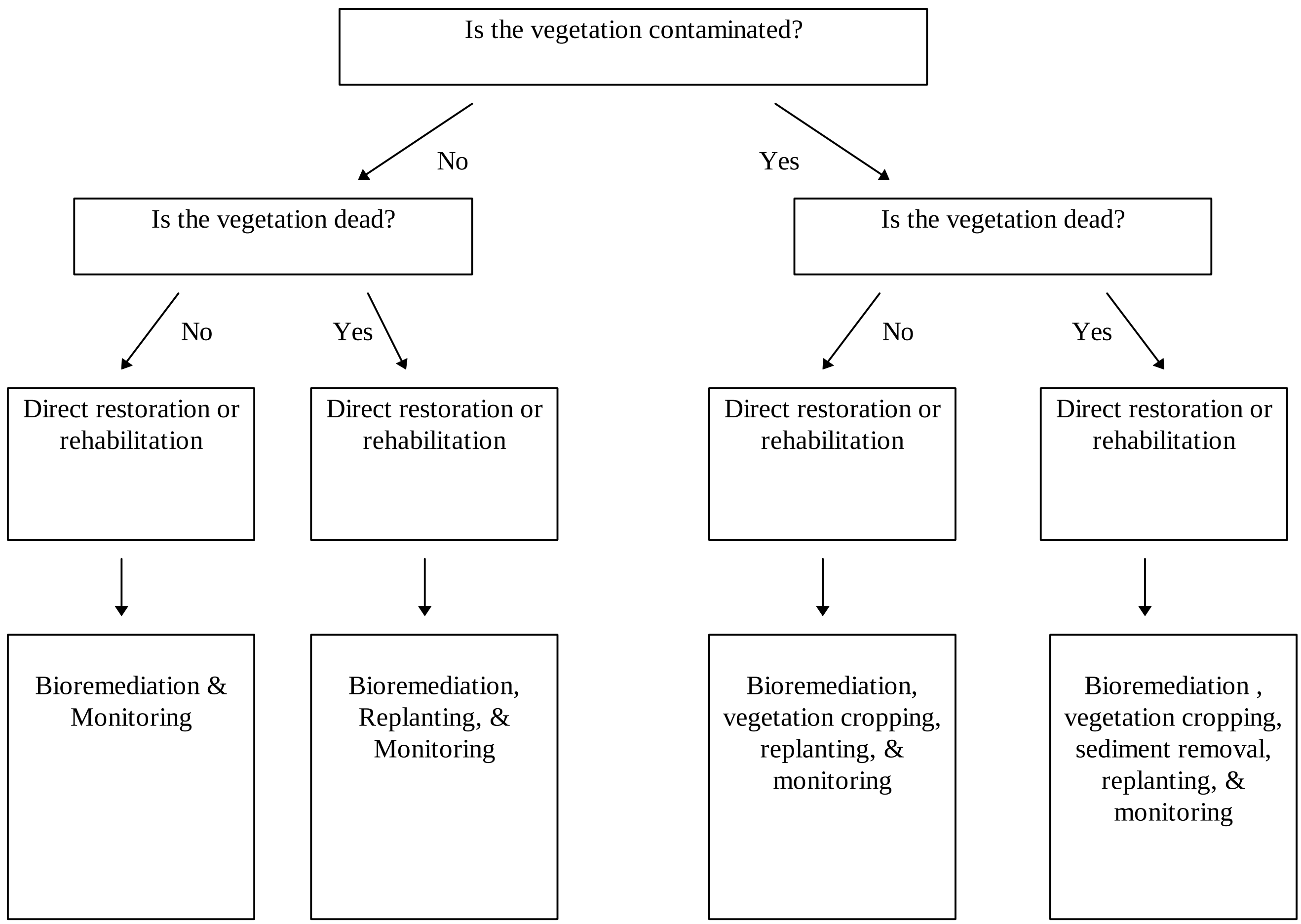

Exhibit 5.12 Decision diagram for restoration alternatives and actions for saltmarsh and freshwater emergent wetlands where oil has penetrated the substrate.

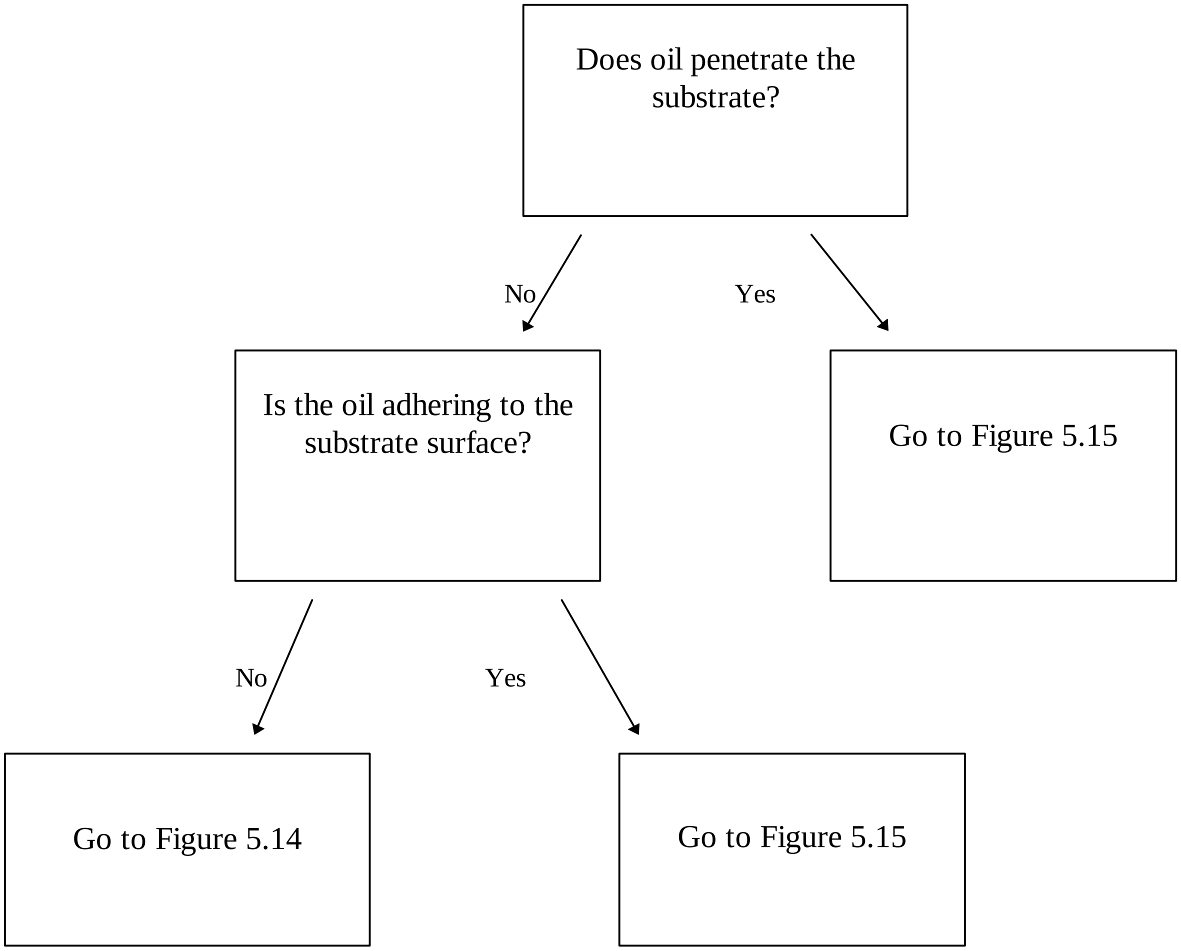

Exhibit 5.13 Decision diagram for the restoration alternatives and actions for mangrove swamps, freshwater scrub-shrub wetlands, and freshwater forested wetlands.

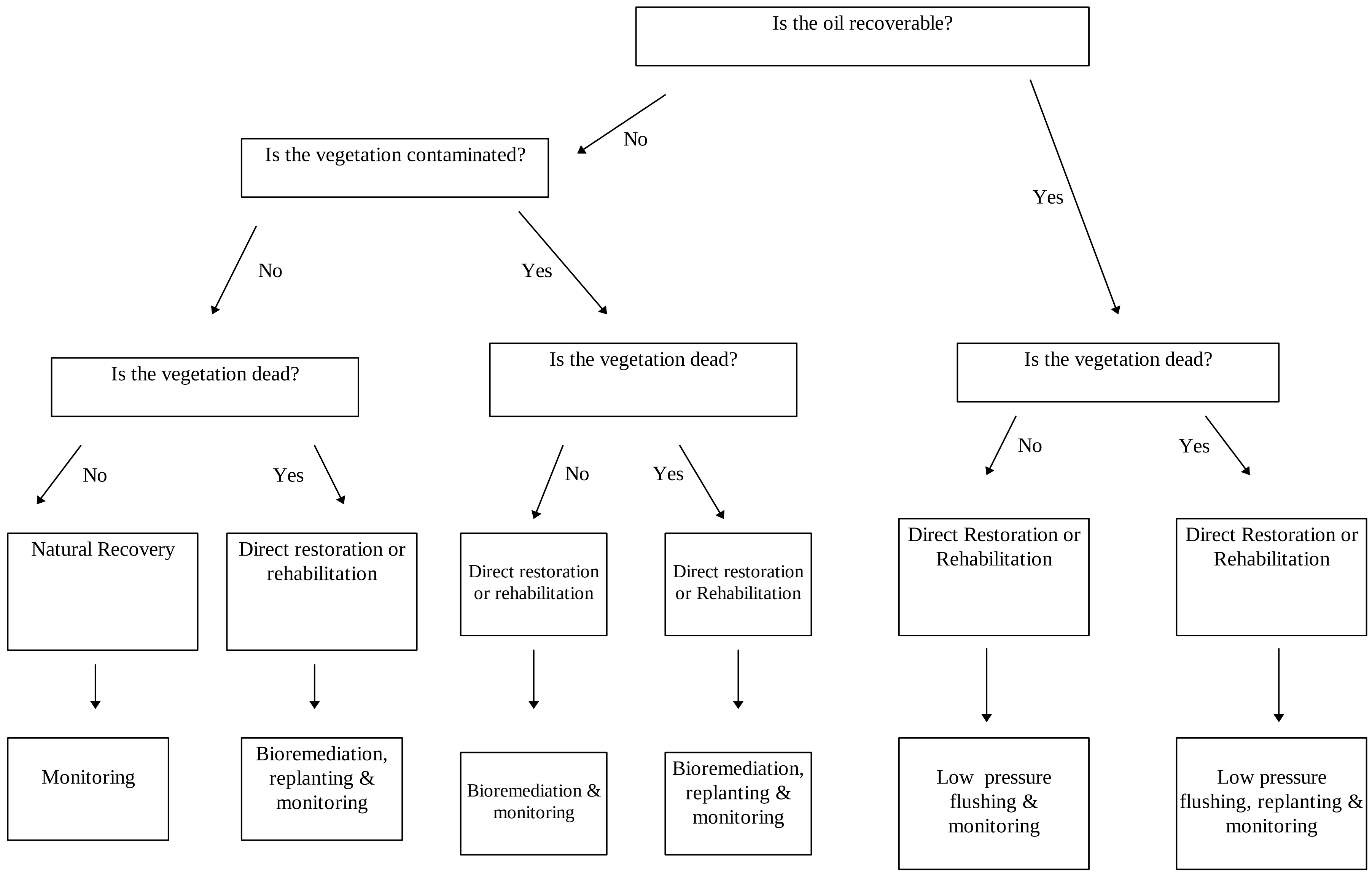

Exhibit 5.14 Decision diagram for restoration alternatives and actions for mangrove swamps, freshwater scrub-shrub wetlands, and freshwater forested wetlands where oil has not penetrated the substrate and is not adhering to the substrate.

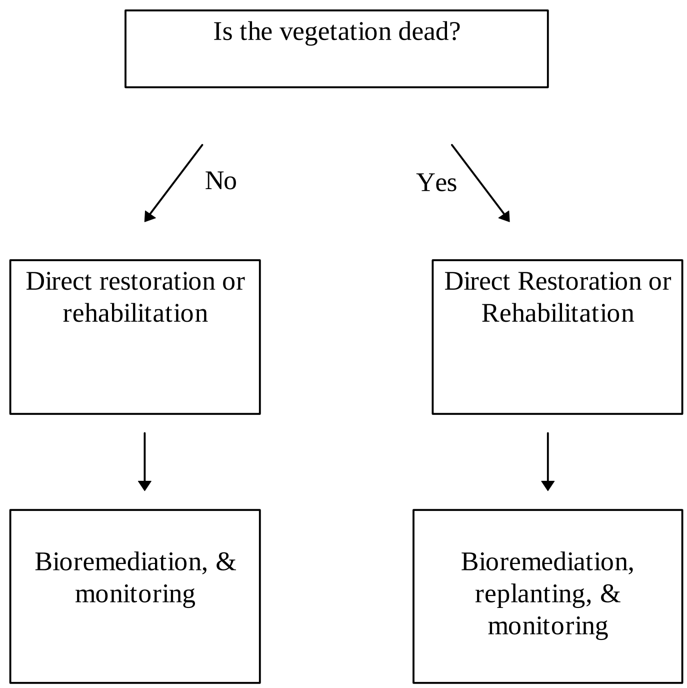

Exhibit 5.15 Decision diagram for restoration alternatives and actions for mangrove swamps, freshwater scrub-shrub wetlands, freshwater forested wetlands where oil may or may not have penetrated but is adhering to the substrate.

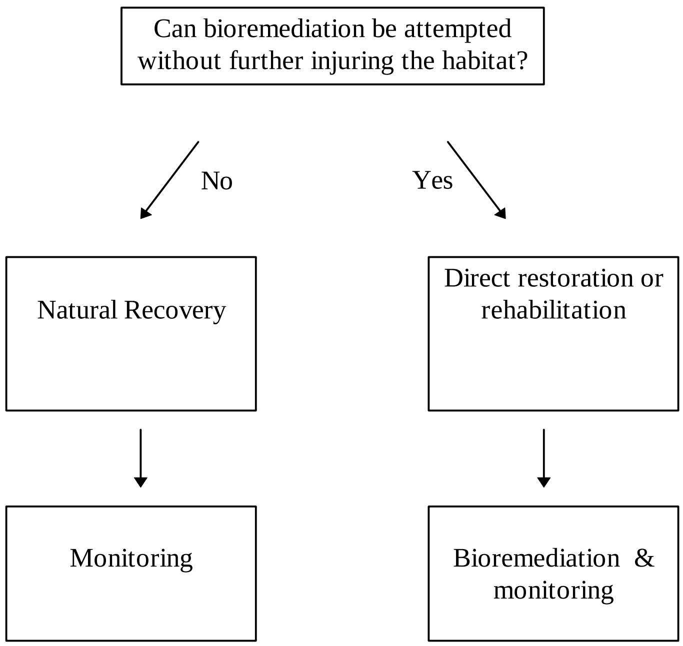

Exhibit 5.16 Decision diagram for restoration alternatives and actions for freshwater bogs and fens.

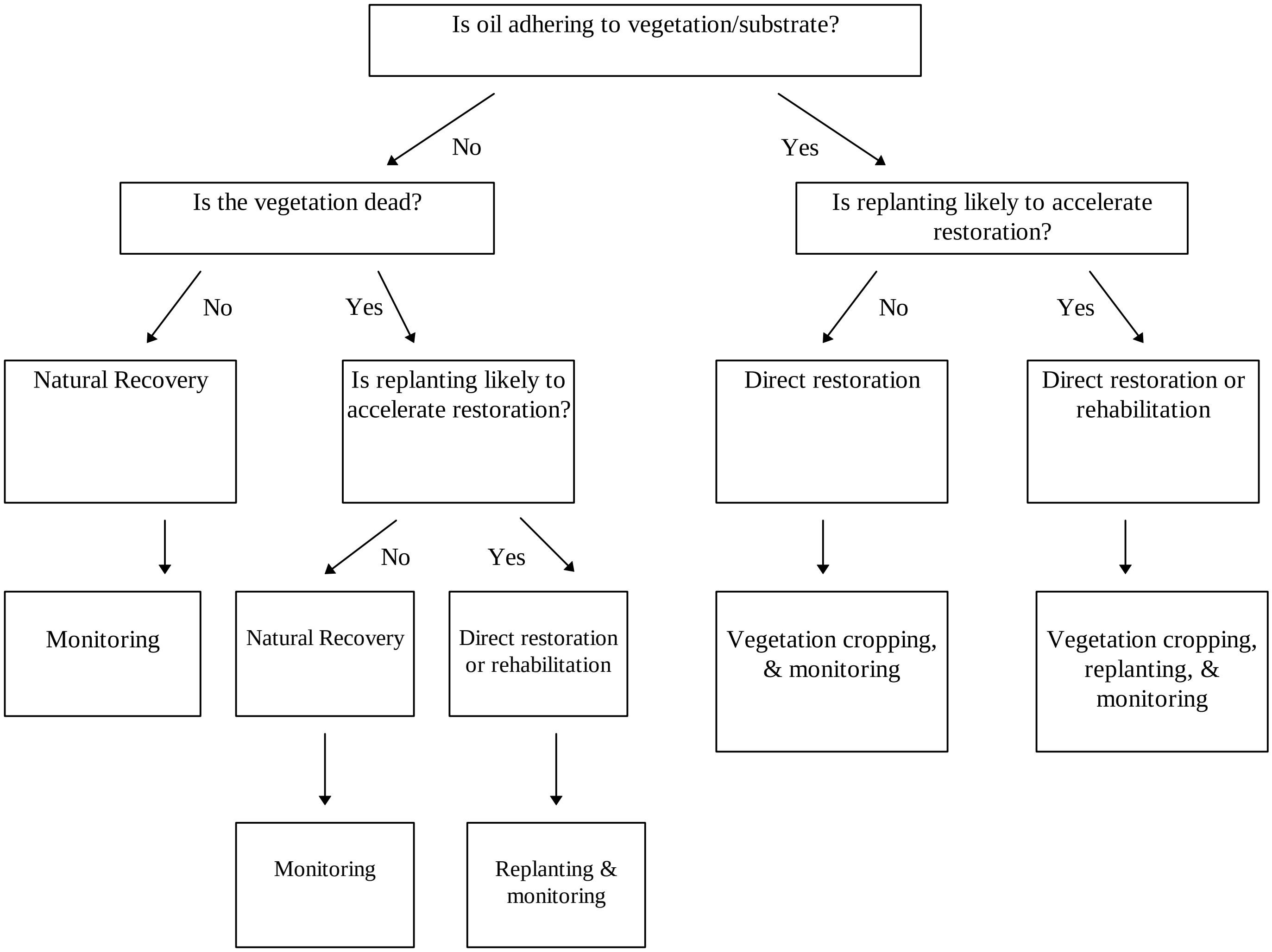

Exhibit 5.17 Decision diagram for restoration alternatives and actions for internal macroalgal beds.

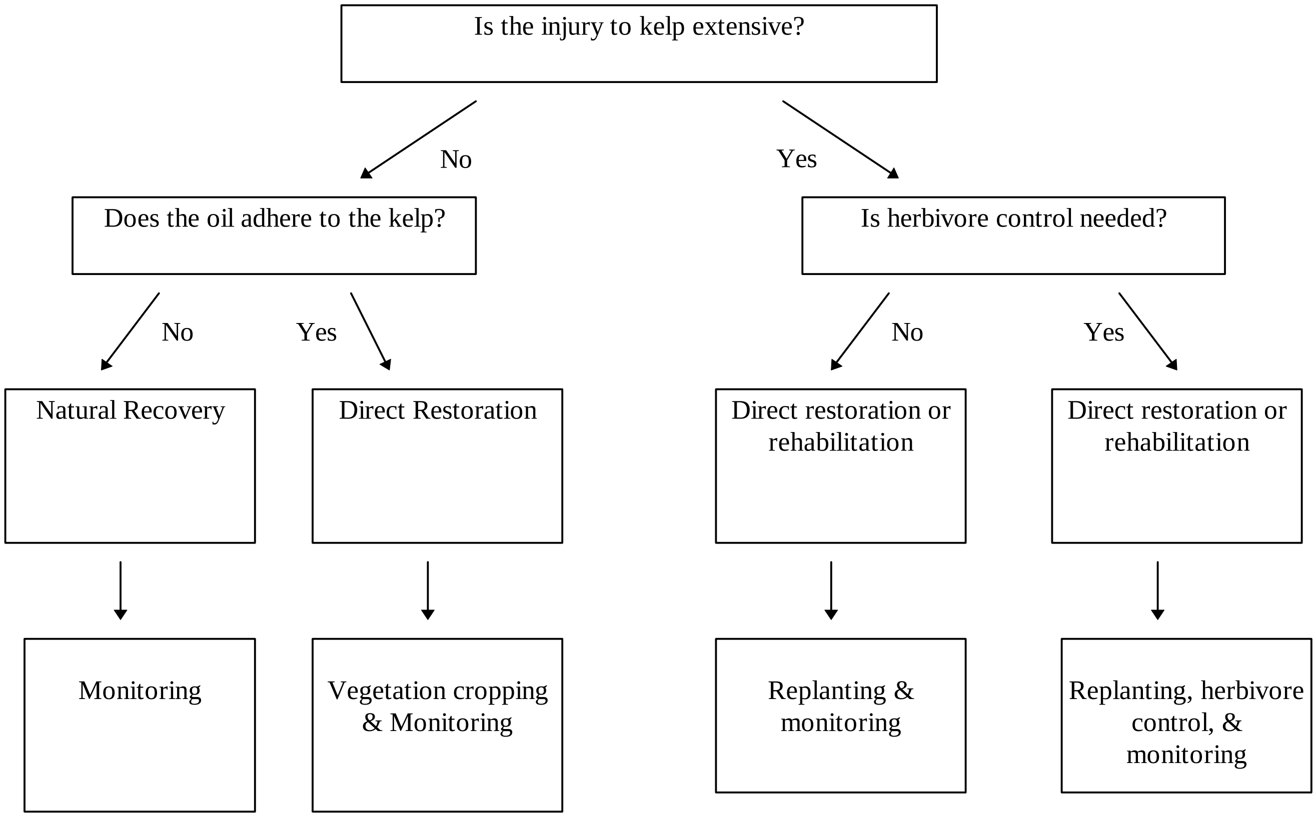

Exhibit 5.18 Decision diagram for restoration alternatives and actions for kelp beds.

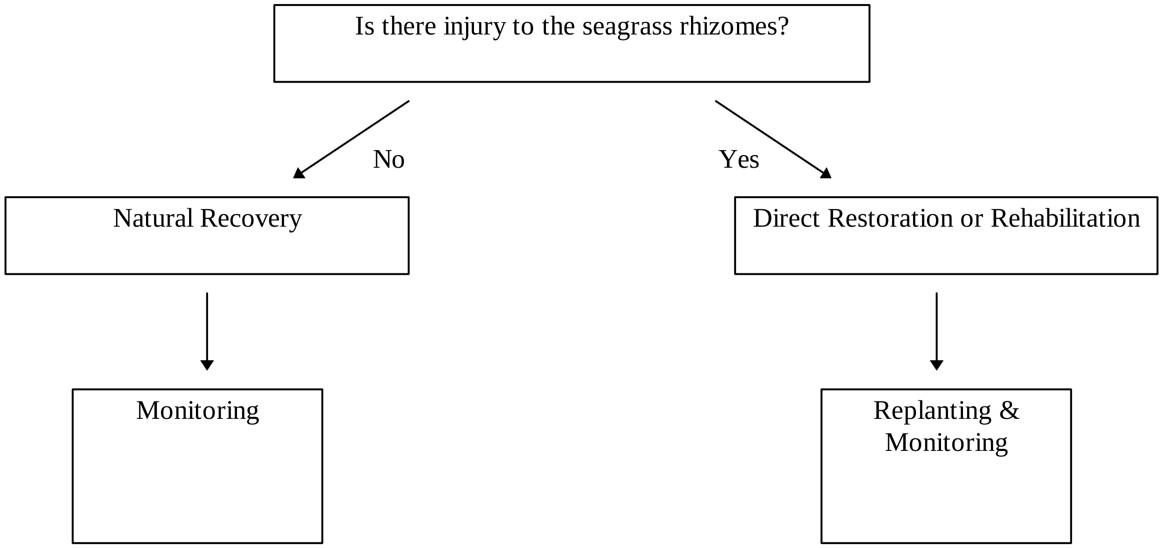

Exhibit 5.19 Decision diagram for restoration alternatives and actions for seagrass beds.

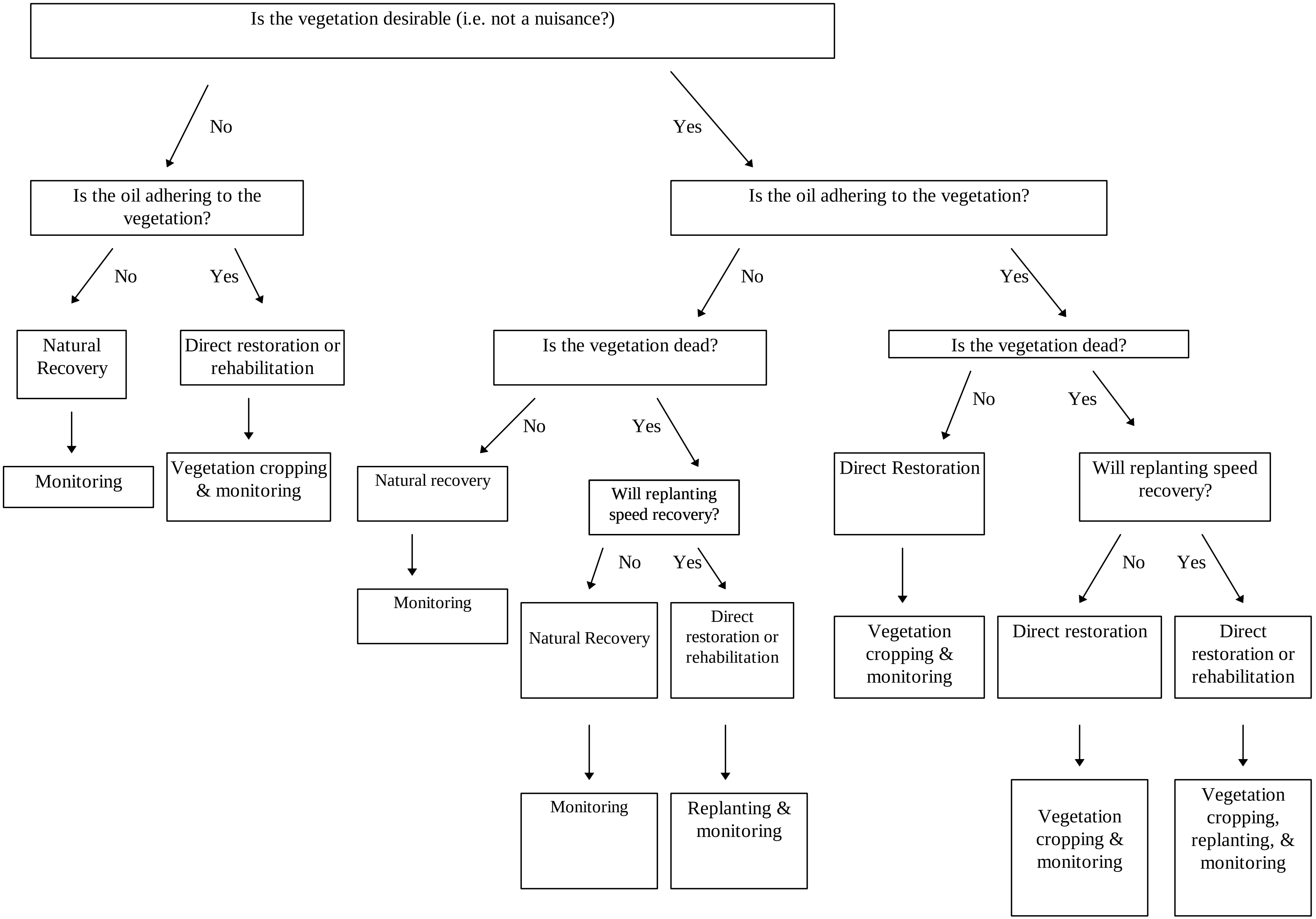

Exhibit 5.20 Decision diagram for restoration alternatives and actions for freshwater aquatic beds.

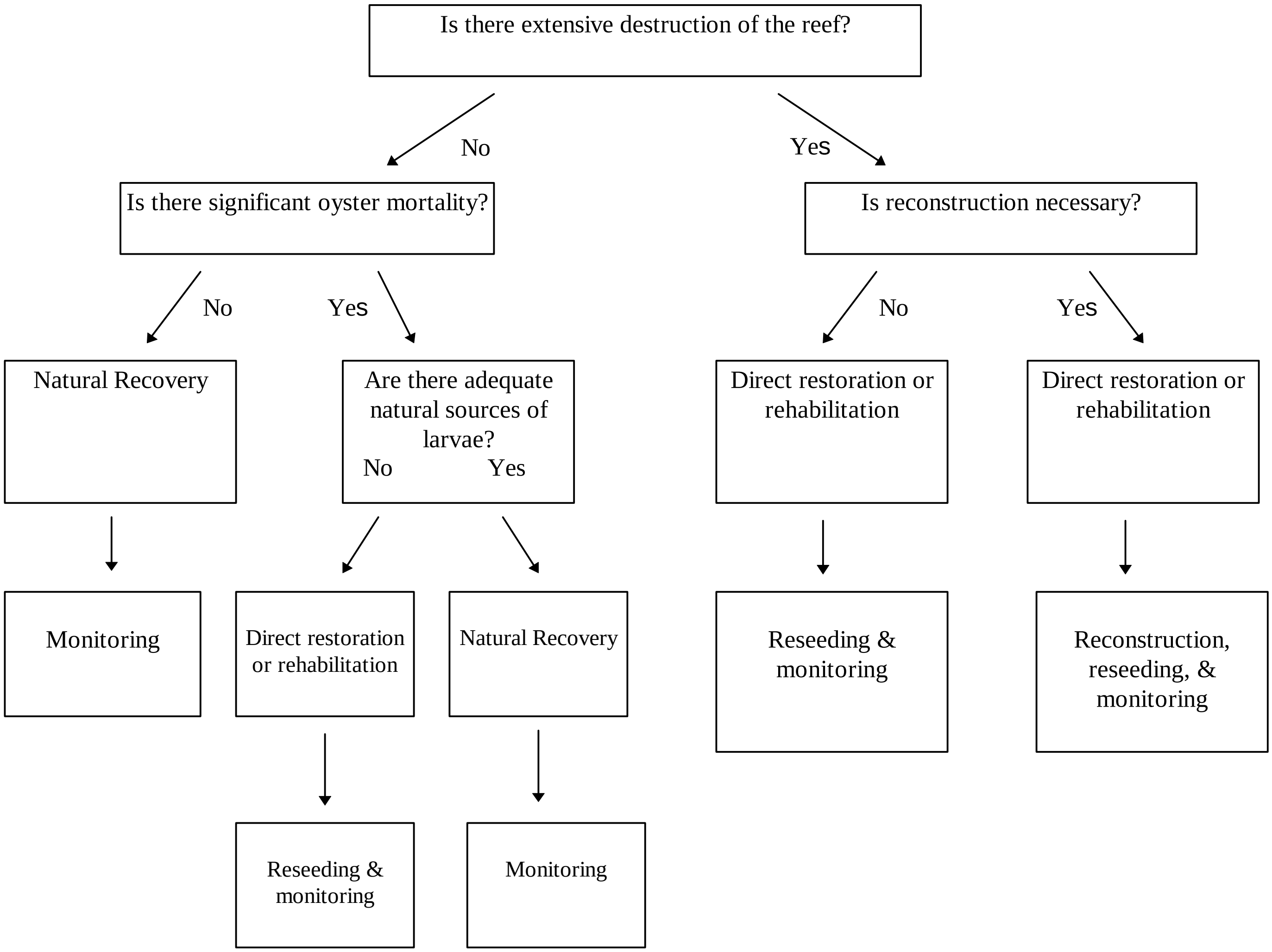

Exhibit 5.21 Decision diagram for restoration alternatives and actions for oyster reefs.

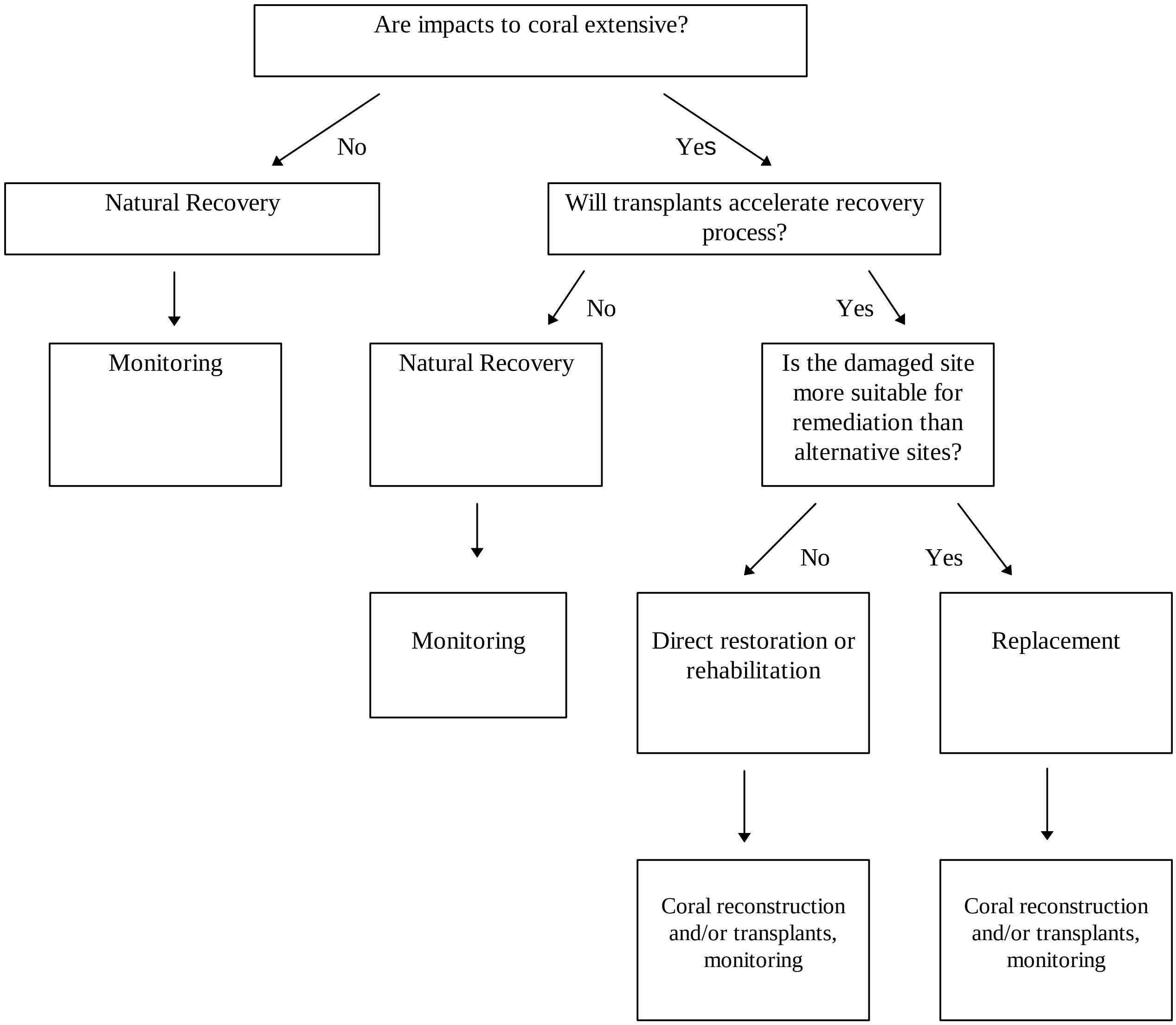

Exhibit 5.22 Decision diagram for restoration alternatives and actions for coral reefs.

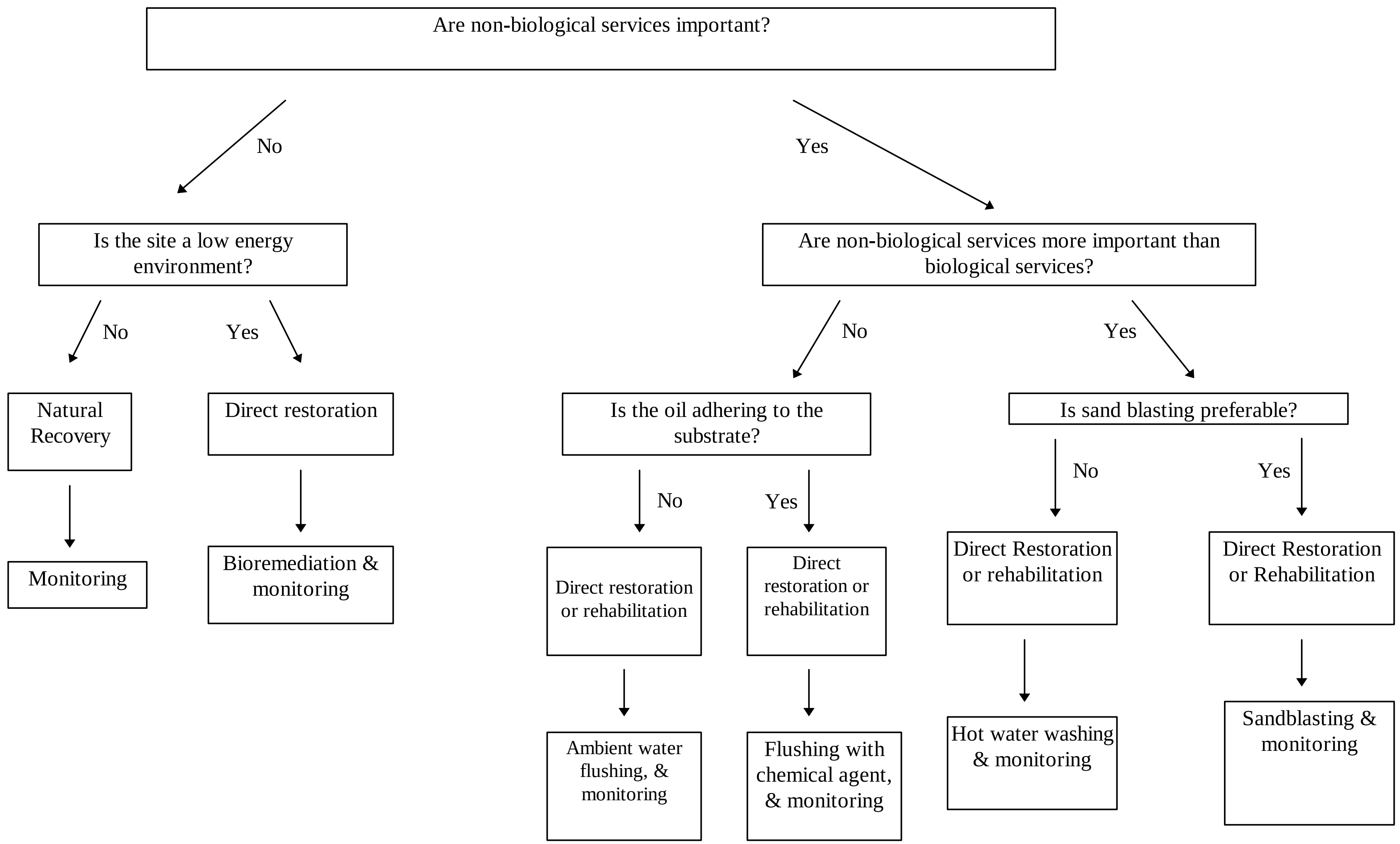

Exhibit 5.23 Decision diagram for restoration alternatives and actions for estuarine, marine and freshwater rocky shores.

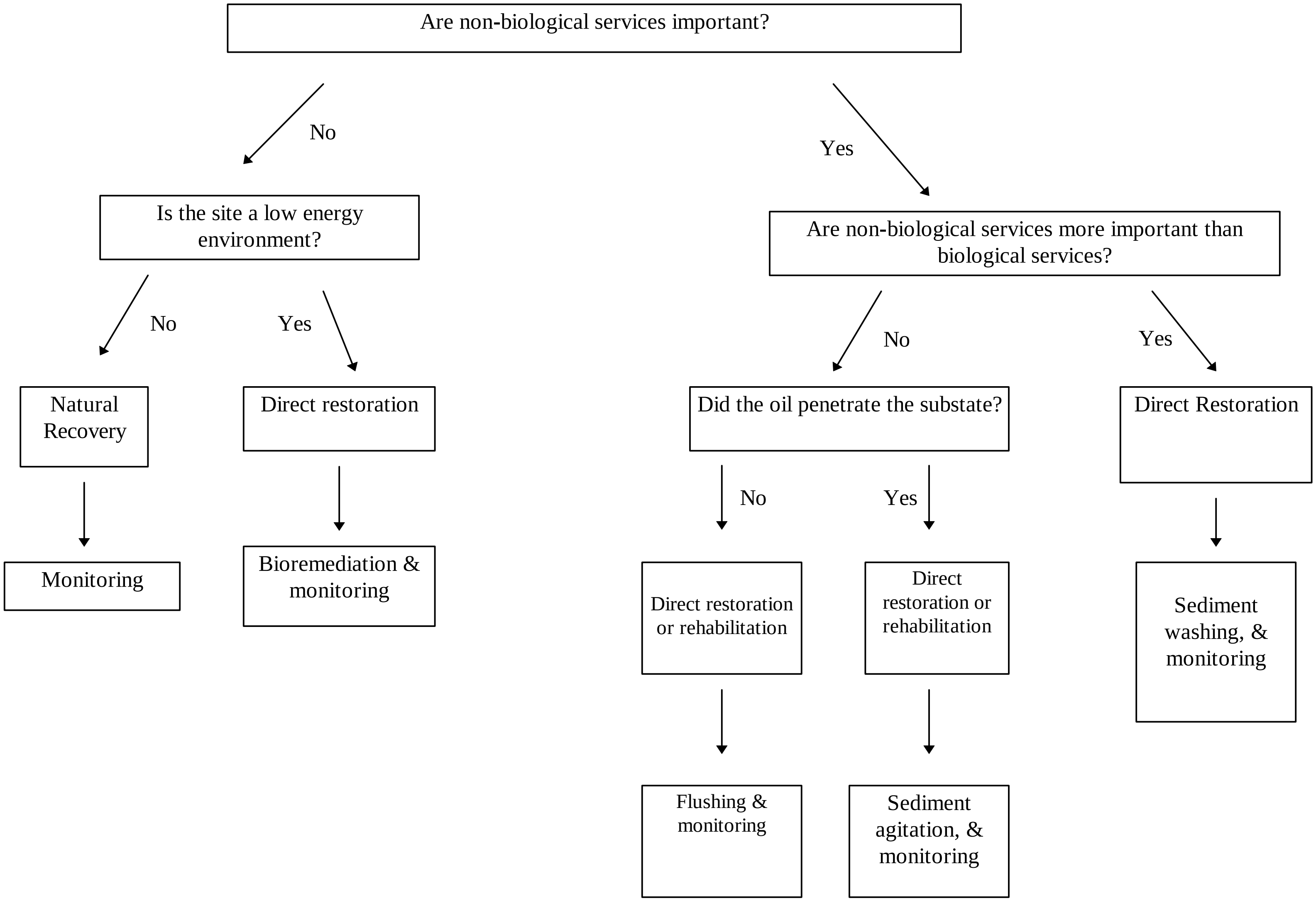

Exhibit 5.24 Decision diagram for the restoration alternatives and actions for estuarine, marine and freshwater cobble-gravel beaches.

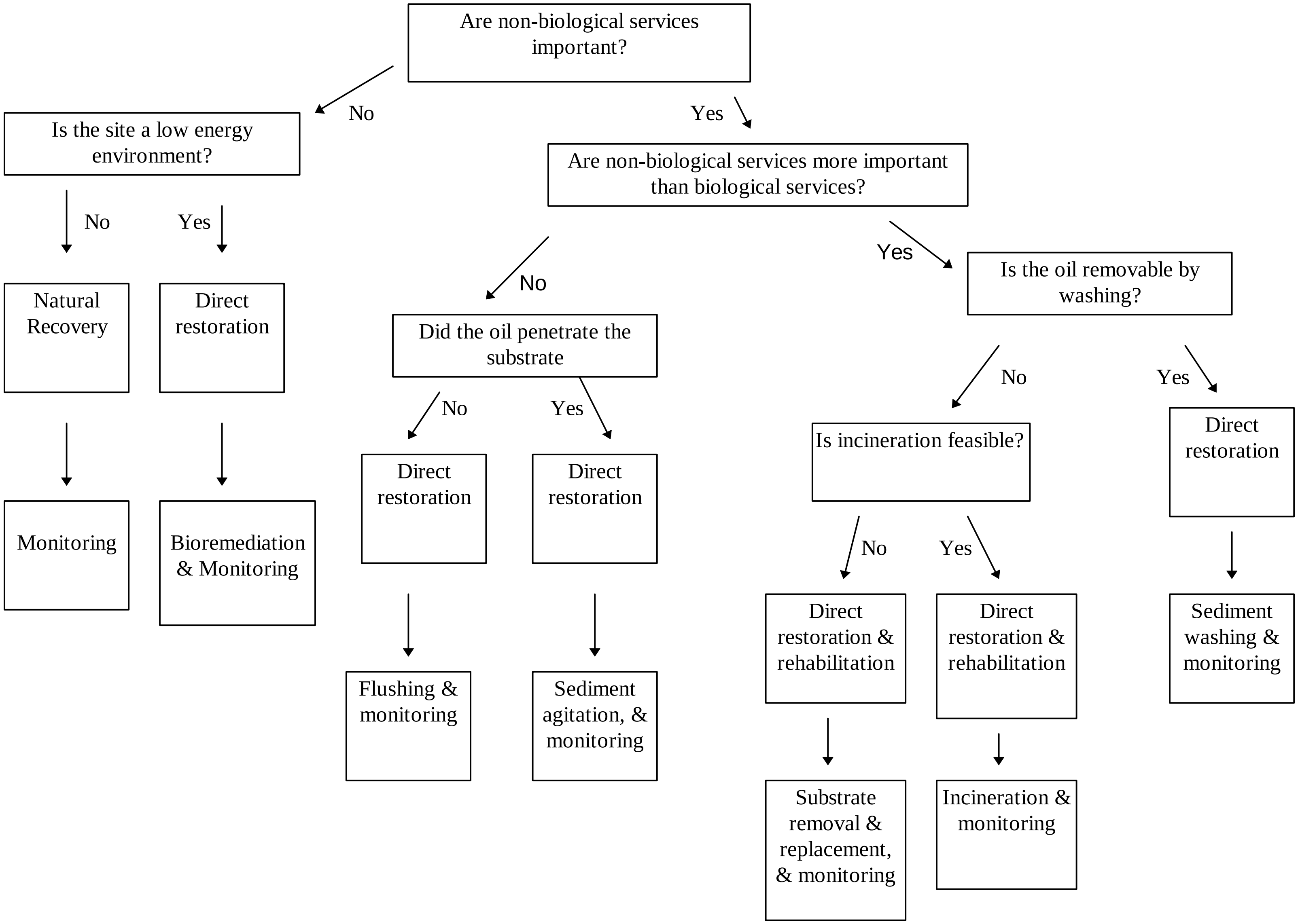

Exhibit 5.25 Decision diagram for restoration alternatives and actions for estuarine, marine and freshwater sand beaches

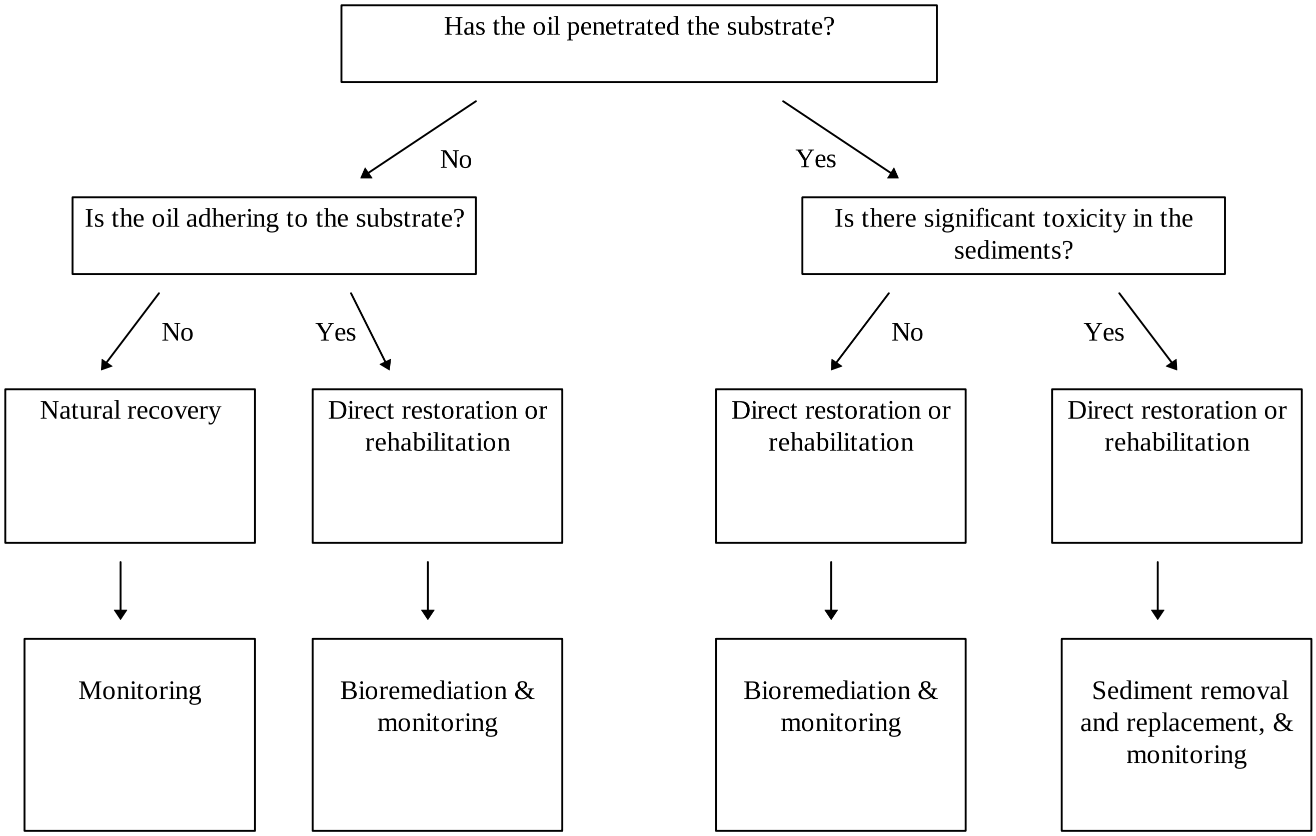

Exhibit 5.26 Decision diagram for the restoration alternatives and actions for estuarine and marine intertidal mud flats and freshwater silt-mud shores.

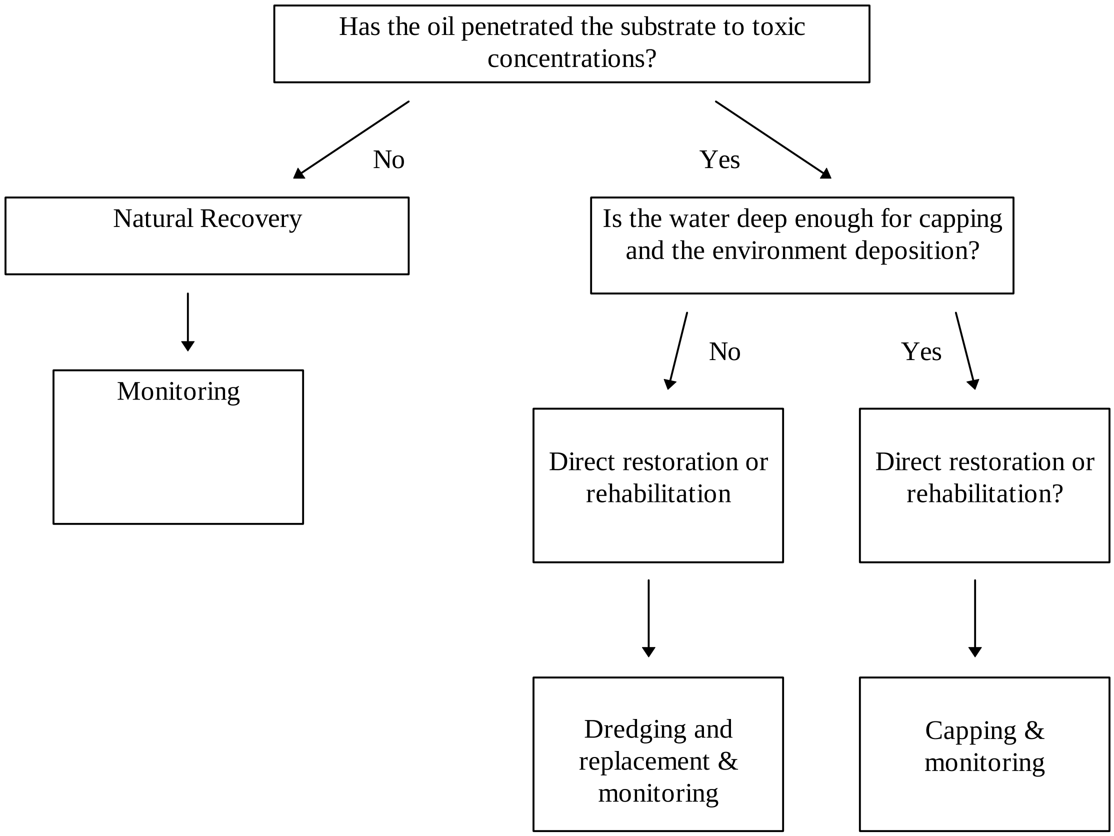

Exhibit 5.27 Decision diagram for the restoration alternatives and actions for estuarine and marine subtidal cobble-gravel, sand and silt-mud bottom, and freshwater sand and silt-mud bottoms.

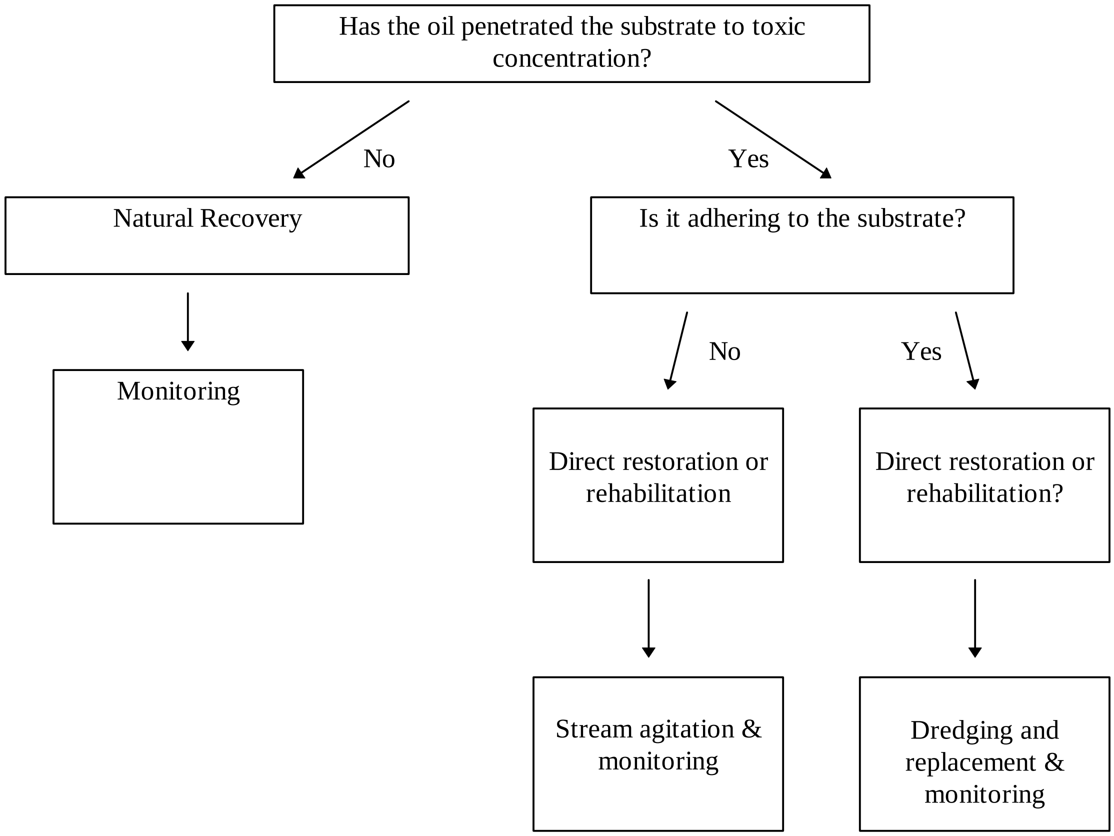

Exhibit 5.28 Decision diagram for the restoration alternatives and actions for freshwater cobble-gravel bottoms.

Exhibit 5.29 Alternatives and actions for restoration of saltmarshes. (M=monitoring costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	Months to a few years	M
Direct Restoration or Rehabilitation	Replanting, monitoring	None	Yes	Months to a few years	10,000 - 45,000 + M
Direct Restoration or Rehabilitation	Vegetative cropping, monitoring	Vegetative cropping from boats	Yes	Months to a few years	32,000 + M
Direct Restoration or Rehabilitation	Vegetative cropping, replanting, monitoring	Vegetative cropping from boats	Yes	Months to a few years	42,000 - 77,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, monitoring	Low pressure flushing from boats	Yes	Months to a few years	11,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, replanting, monitoring	Low pressure flushing from boats	Yes	Months to a few years	21,000-56,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing,vegetative cropping, monitoring	Low pressure flushing and vegetative cropping from boats	Yes	Months to a few years	43,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, vegetative cropping, replanting, monitoring	Low pressure flushing and vegetative cropping from boats	Yes	Months to a few years	53,000 - 88,000 + M
Direct Restoration or Rehabilitation	Bioremediation, monitoring	Bioremediation from air or boats	Bioremediation in developmental stage	Months to a few years	1300 + M
Direct Restoration or Rehabilitation	Bioremediation, replanting, monitoring	Bioremediation done from air or boats	Bioremediation in developmental stage	Months to a few years	11,000-46,000 + M

Exhibit 5.29 (continued)

Alternative	**Actions**	**Restrictions to be Effective**	**Technical and Operational Feasibility**	**Effectivenes s and Success: Recovery Time**	**Cost 1992 $/ha**
Direct Restoration or Rehabilitation	Vegetative cropping, bioremediation, monitoring	Vegetative cropping from boats; Bioremediation from boats or air	Bioremediation in development stage	Months to a few years	33,000 + M
Direct Restoration or Rehabilitation	Vegetative cropping, bioremediation, replanting, monitoring	Vegetative cropping from boats; Bioremediation from boats or air	Bioremediation in developmental stage	Months to a few years	43,000-78,000 + M
Direct Restoration or Rehabilitation	Vegetative cropping, bioremediation, sediment replacement, replanting, monitoring	Vegetative cropping from boats; Bioremediation from boats or air	Bioremediation in developmental stage; sediment replacement feasible only where equipment has access	Months to a few years	123,000-158,000 + M
Direct Restoration or Rehabilitation	Supplemental erosion control	None	Yes	Months	4-1600 per linear meter + M
Replacement	Enhancement	Appropriate site	Yes	Years, depends on specific actions	highly variable depending on site; monitoring costs should be included
Replacement	Creation	Appropriate site	Yes	Years to decades	highly variable depending on site; monitoring costs should be included

Exhibit 5.30 Alternatives and actions for restoration of mangrove swamps. (M=monitoring costs, see text for explanation).

Alternatives	**Actions**	**Restrictions to be Effective**	**Technical and Operational Feasibility**	**Effectiveness and Success: Recovery Time**	**Cost 1992 $/ha**
Natural Recovery	Monitoring	None	Yes	Years to decades	M
Direct Restoration or Rehabilitation	Bioremediation, monitoring	Bioremediation from air or boats	Bioremediation in development stage	Decades	1300 + M
Direct Restoration or Rehabilitation	Bioremediation, replanting, monitoring	Bioremediation from air or boats	Bioremediation in developmental stage	Decades	3700-455,000 + M
Direct Restoration or Rehabilitation	Low pressure, flushing, monitoring	Low pressure flushing from boats	Yes	Decades	11,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, replanting monitoring	Low pressure flushing from boats	Yes	Decades	13,000-465,000 + M
Replacement	Enhancement	Appropriate site	Yes	Decades	2,400-454,00 + M
Replacement	Creation	Appropriate site	Yes	Decades	Highly variable; no reported costs; monitoring costs should be included

Exhibit 5.31 Alternatives and actions for restoration of freshwater emergent wetlands. (M=Monitoring costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	Months to years	M
Direct Restoration or Rehabilitation	Replanting, monitoring	None	Yes	Years	11,000-38,000 + M
Direct Restoration or Rehabilitation	Vegetative cropping, monitoring	Vegetative cropping from boats	Yes	Years	32,000 + M
Direct Restoration or Rehabilitation	Vegetative cropping, replanting, monitoring	Vegetative cropping from boats	Yes	Years	43,000 - 70,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, monitoring	Low pressure flushing from boats	Yes	Years	11,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, replanting, monitoring	Low pressure flushing from boats	Yes	Years	22,000-49,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, vegetative cropping, monitoring	Low pressure flushing and vegetative cropping from boats	Yes	Years	43,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, vegetative cropping, replanting, monitoring	Low pressure flushing and vegetative cropping from boats	Yes	Years	54,000 - 81,000 + M
Direct Restoration or Rehabilitation	Bioremediation, monitoring	Bioremediation from air or boats	Bioremediation in developmental stage	Years	1300 + M
Direct Restoration or Rehabilitation	Bioremediation, replanting, monitoring	Bioremediation from air or boats	Bioremediation in developmental stage	Years	12,000-39,000 + M

Exhibit 5.31 (continued)

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Direct Restoration or Rehabilitation	Vegetative cropping, bioremediation, monitoring	Vegetative cropping and bioremediation from boats or air	Bioremediation in developmental stage	Years	33,000 + M
Direct Restoration or Rehabilitation	Vegetative cropping, bioremediation, replanting, monitoring	Vegetative cropping and bioremediation from boats or air	Bioremediation in developmental stage	Years	44,000-71,000 + M
Direct Restoration or Rehabilitation	Vegetative cropping, bioremediation, sediment replacement, replanting, monitoring	Vegetative cropping and bioremediation from boats or air	Bioremediation in developmental stage; sediment replacement feasible only where equipment has access	Years	124,000-151,000 + M
Direct Restoration or Rehabilitation	Supplemental erosion control	None	Yes	Years	4-1600 per linear meter + M
Replacement	Enhancement	Appropriate site	Yes	Years	Highly variable depending on site; monitoring costs should be included
Replacement	Creation	Appropriate site	Yes	Years	Highly variable depending on site; monitoring costs should be included

Exhibit 5.32 Alternatives and actions for restoration of freshwater scrub-shrub wetlands. (M=monitoring costs, see text for explanation).

Alternatives	**Actions**	**Restrictions to be Effective**	**Technical and Operational Feasibility**	**Effectiveness and Success: Recovery Time**	**Cost 1992 $/ha**
Natural Recovery	Monitoring	None	Yes	Months to years	M
Direct Restoration or Rehabilitation	Bioremediation, monitoring	Bioremediation from boats or air	Bioremediation in developmental stage	Years	1300 + M
Direct Restoration or Rehabilitation	Bioremediation, replanting, monitoring	Bioremediation from boats or air	Bioremediation in developmental stage	Years	No cost data reported for replanting; costs above apply
Direct Restoration or Rehabilitation	Low pressure flushing, monitoring	Low pressure flushing from boats	Yes	Years	11,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, replanting, monitoring	Low pressure flushing from boats	Yes	Years	No cost data reported for replanting; costs above apply
Replacement	Enhancement	Appropriate site	Yes	Years	No cost data reported; monitoring costs should be included
Replacement	Creation	Appropriate site	Yes	Years	No cost data reported; monitoring costs should be included

Exhibit 5.33 Alternatives and actions for restoration of forested wetlands. (M=monitoring costs, see text for explanation).

Alternatives	**Actions**	**Restrictions to be Effective**	**Technical and Operational Feasibility**	**Effectiveness and Success: Recovery Time**	**Cost 1992 $/ha**
Natural Recovery	Monitoring	None	Yes	Decades	M
Direct Restoration or rehabilitation	Bioremediation, monitoring	Bioremediation from boats or air	Bioremediation in development stage	Decades	1300 + M
Direct Restoration or Rehabilitation	Bioremediation, replanting, monitoring	Bioremediation from boats or air	Bioremediation in development stage	Decades	1300-78,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, monitoring	Low pressure flushing from boats	Yes	Decades	11,000 + M
Direct Restoration or Rehabilitation	Low pressure flushing, replanting, monitoring	Low pressure flushing from boats	Yes	Decades	11,000-88,000 + M
Replacement	Enhancement	Appropriate Site	Yes	Decades	Highly variable depending on site; monitoring costs should be included
Replacement	Creation	Appropriate site	Yes	Decades	Highly variable depending on site; monitoring costs should be included

Exhibit 5.34 Alternatives and actions for restoration of intertidal macroalgal beds. (M=monitoring costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	Up to 1 year for minor injury; 5-10 years for great injury	M
Direct Restoration	Vegetative cropping, monitoring	None	Not demonstrated	5-10 years	No cost data identified, monitoring costs should be included
Direct Restoration or Rehabilitation	Replanting, monitoring	None	Not demonstrated	Untested or unknown	No cost data identified, monitoring costs should be included
Direct Restoration or Rehabilitation	Vegetative cropping, replanting, monitoring	None	Not demonstrated	Untested	No cost data identified, monitoring costs should be included
Replacement	Replanting, monitoring	Appropriate site	Not demonstrated	Untested	No cost data identified, monitoring costs should be included

Exhibit 5.35 Alternatives and actions for restoration of kelp beds. (M=Monitoring costs, see text for explanation).

Alternatives	**Actions**	**Restrictions to be Effective**	**Technical and Operational Feasibility**	**Effectiveness and Success: Recovery Time**	**Cost 1992 $/ha**
Natural Recovery	Monitoring	None	Yes	One to several years depending on level of injury	M
Direct Restoration	Vegetative cropping, monitoring	None	Yes	One to several years depending on level of injury	No cost data identified
Direct Restoration or Rehabilitation	Replanting, monitoring	None	Yes	Kelp: ±2 years (depends on planting density, etc.) animal community: unknown	1500-3100 + M
Direct Restoration or Rehabilitation	Replanting, herbivore control, monitoring	None	Feasibility of herbivore control unknown	Kelp: ±2 years (depends on planting density, etc.) animal community: unknown	1500-3100 + M plus costs of herbivore control
Replacement	Off-site planting, monitoring	Appropriate site	Yes	Kelp: ±2 years (depends on planting density, etc.) animal community: unknown	1500-3100 M
Replacement	Off-site planting, herbivore control, monitoring	Appropriate site	Feasibility of herbivore control unknown	Kelp: ±2 years (depends on planting density, etc.) animal community: unknown	1500-3100 + M plus costs of herbivore control

Exhibit 5.36 Alternatives and actions for restoration of seagrass beds. (M=monitoring costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	1+ year for vegetation; whole community unknown	M
Direct Restoration or Rehabilitation	Replanting, monitoring	Substrate should not be significantly disturbed	Yes	2+ years depending on species, planting density, level of injury to substrate. Animal recovery will vary with availability of nearby sources for migration.	8,000-200,000 + M
Replacement	Off-site replanting, monitoring	Only in previously vegetated sites	Yes	2+ years depending on species, planting density, appropriateness of site selected. Animal recovery will vary with availability of nearby sources for migration.	8,000-200,000 + M

Exhibit 5.37 Alternatives and actions for restoration of freshwater aquatic beds. (M=monitoring costs, see text for explanation).

Alternatives	**Actions**	**Restrictions to be Effective**	**Technical and Operational Feasibility**	**Effectiveness and Success: Recovery Time**	**Cost 1992 $/ha**
Natural Recovery	Monitoring	None	Yes	Up to 1 year	M
Direct Restoration	Vegetative cropping, Monitoring	None	Yes	±1 year	Costs unknown +M
Direct Restoration or Rehabilitation	Replanting, monitoring	None	Availability of appropriate species	1 to several years	Costs unknown +M
Direct Restoration or Rehabilitation	Vegetative cropping, replanting, monitoring	None	Availability of appropriate species	1 to several years	Costs unknown +M
Replacement	Replanting, monitoring	Appropriate site	Availability of appropriate species	1 to several years	Costs unknown +M

Exhibit 5.38 Alternatives and actions for restoration of oyster reefs. (M=Monitoring costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Natural reseeding of oyster bed and monitoring	Natural source of larvae	Yes	1-2 1/2 years	M
Natural Recovery	Flushing, monitoring	Clean water	Yes	Days to weeks?	M
Direct Restoration or Rehabilitation	Reseeding and monitoring	None	Yes	1-2 1/2 years	1200 + M
Direct Restoration or Rehabilitation	Reconstruction, reseeding, monitoring	None	Yes	1-2 1/2 years	3000-15,000 + M
Replacement	Reseeding unproductive area and monitoring	Suitable substrate	Yes	1-2 1/2 years	1200 + M
Replacement	Reconstruction, reseeding, and monitoring	Previous site	Yes	1-2 1/2 years	3000-15000 + M
Replacement	Creation	Appropriate site	Yes	1-2 1/2 years	3000-15000+ M

Exhibit 5.39 Alternatives and actions for restoration of coral reefs. (M=monitoring costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	1-10 years (longer if damage is extensive)	M
Direct Restoration or Rehabilitation	Coral reconstruction and/or transplants & monitoring	None	Yes	10 years to several decades	2,368,000 + M
Replacement	Off-site coral reconstruction and/or transplants & monitoring	Existing reef with nearby donor site	Yes	10 years to several decades	2,368,000 + M

Exhibit 5.40 Alternatives and actions for restoration of estuarine, marine, and freshwater rocky shores. (M=monitoring, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	Dependent on wave action and oil type. High energy shore-weeks to 5 years; sheltered low energy shore 5-10 years	M
Direct Restoration or Rehabilitation	Bioremediation, monitoring	Fertilizer will only remain on shore in low energy areas	Access to shore	To date, no gain in recovery time over natural recovery was demonstrated	24,000-144,000 + M
Direct restoration or rehabilitation	Ambient temperature, low pressure flushing; monitoring	Minimize trampling of biota	Access to shore; availability of equipment	Removes oil without killing additional flora and fauna. Recovery 5-10 years.	52,000-65,000 + M
Direct restoration or rehabilitation	Flushing with chemical agent, monitoring	Minimize trampling of biota	Access to shore; availability of equipment	If non-lethal to biota, recovery in 5-10 years likely.	52,000-65,000 + M
Direct Restoration or Rehabilitation	Hot water, high pressure washing, monitoring	None	Access to shore; availability of equipment	Removes oil but causes further injury to flora and fauna. Longer recover time than for natural recovery.	52,000-65,000 + M
Direct restoration or rehabilitation	Sand blasting, monitoring	None	Access to shore; availability of equipment	Removes oil but causes further injury to flora and fauna. Longer recovery time than for natural recovery.	235,000 + M

Exhibit 5.41 Alternatives and actions for restoration of estuarine, marine, and freshwater cobble-gravel beaches. (M=monitoring costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	5-10 years	M
Direct Restoration or Rehabilitation	Medium pressure flushing, monitoring	None	Access to beach	Can force oil deeper into substrate and increase recovery time	52,000-65,000 +M
Direct Restoration or Rehabilitation	Sediment washing, monitoring	None	Access to beach, availability of "rock washer"	Causes mortality; recovery rates not yet available	23,000-396,000 + M
Direct Restoration or Rehabilitation	Sediment agitation, monitoring	None	Access to beach	Moves oiled substrate to area of wave action where natural recovery is enhanced.	95,000 + M
Direct restoration or rehabilitation	Bioremediation, monitoring	None	Access to beach	5-10 times faster than natural (1 case in Alaska); still under research	24,000-144,000 + M

Exhibit 5.42 Alternatives and actions for restoration of estuarine, marine, and freshwater sand beaches. (M=monitoring costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	3-5 years	M
Direct Restoration or Rehabilitation	Flushing	None	Access to beach	Effective in removing oil	52,000-65,000 + M
Direct Restoration or Rehabilitation	Sediment agitation	None	Access to beach	Effective in exposing oiled substrate for natural recovery; 3-5 years after completion	95,000 + M
Direct Restoration or Rehabilitation	Sediment washing	None	Access to beach; availability of sediment washing equipment	Effective in removing oil; no recovery data available.	23,000-247,000 + M
Direct Restoration or Rehabilitation	Substrate removal and replacement	None	Access to beach	Effective in removing oil	106,000 + M
Direct Restoration or Rehabilitation	Bioremediation	None	Access to beach; bioremediation development	Recovery may be better than for natural recovery; time not determined; under research	24,000-144,000 + M
Direct Restoration or Rehabilitation	Incineration, monitoring	None	Access to beach; availability of equipment	3-5 years after completion	860,000-1,110,000 + M

Exhibit 5.43 Alternatives and actions for restoration of estuarine and marine intertidal mud flat and freshwater silt-mud shores. (M=monitoring costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	1 to 5 years	M
Direct Restoration or rehabilitation	Sediment removal and replacement, monitoring	None	Yes	2 years following restoration action	106,000 + M
Direct Restoration or Rehabilitation	Bioremediation, monitoring	Minimize traffic on substrate	Developmental technique	Likely to be 2-5 years following restoration action	24,000-144,000 + M

Exhibit 5.44 Alternatives and actions for restoration of estuarine, marine, and freshwater rock bottom. (M=monitoring Costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	1-3 years	M

Exhibit 5.45 Alternatives and actions for restoration of estuarine and marine subtidal cobble-gravel, sand and silt-mud bottoms, and freshwater sand and silt-mud bottoms. (M=monitoring costs, see text for explanation).

Alternatives	**Actions**	**Restrictions to be Effective**	**Technical and Operational Feasibility**	**Effectiveness and Success: Recovery Time**	**Cost 1992 $/ha**
Natural Recovery	Monitoring	None	Yes	2-3 years	M
Direct Restoration or rehabilitation	Dredging and replacement, monitoring	None	Yes	2-5 years	0.32 - 20.20/m^3 of material removed plus capping costs; plus costs of monitoring
Direct Restoration or Rehabilitation	Capping, monitoring	Depositional environment, deep water	Yes	2-5 years	1.29 - 4.25/m^3 of capping material; plus costs of monitoring

Exhibit 5.46 Alternatives and actions for restoration of freshwater cobble-gravel bottoms. (M=monitoring costs, see text for explanation).

Alternatives	Actions	Restrictions to be Effective	Technical and Operational Feasibility	Effectiveness and Success: Recovery Time	Cost 1992 $/ha
Natural Recovery	Monitoring	None	Yes	Recovery within 1 year (1 case study)	M
Direct Restoration or Rehabilitation	Streambed agitation, monitoring	None	Yes	Recovery within 1 year (1 case study)	300 + M
Direct Restoration or Rehabilitation	Dredging and replacement, monitoring	None	Yes	Recovery likely to require 2-3 years	0.32-20.20/m^3 of material removed; plus 1.29-4.25/m^3 for replacement sediments; plus monitoring costs